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The Riverside Science Series

VOLUME I.

A CENTURY OF ELECTRICITY

By T. C. MENDENHALL

The Riverside Science Series

A CENTURY OF ELECTRICITY

BY

Thomas Corwin

T. C. MENDENHALL

SUPERINTENDENT U. S. COAST AND GEODETIC SURVEY

BOSTON AND NEW YORK
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PREFACE.

A HUNDRED years have elapsed since the experiment of an Italian philosopher inaugurated a new era in physical science. The industrious cultivation of the new electricity from that day to the present has been so fruitful of results, that even the specialist has found difficulty in keeping pace with its development. Within a few years it has found its way into the household, and hundreds of thousands of intelligent people have come to have some personal familiarity with its use. It is believed that this familiarity has not "bred contempt," but rather that it has excited a desire, on the part of many, to know something of the fundamental principles which underlie its numerous applications, and to learn something of the evolution of these principles.

In this belief, the author has endeavored to sketch the growth of the science of electricity, and its principal applications. The book is not a history of the science, nor is it a scientific treatise; but the author trusts, that, as far as it goes, it is not far wrong in either its history or its science. The use of technical language has been avoided as far as possible; and the effort has been to enable the intelligent reader, unfamiliar with the nomenclature of the science, to understand the more important phases of its development, and to give him such a knowledge of its fundamental principles as will enable him to comprehend the meaning of what he sees in electrical devices, with which he almost daily comes in contact.

It has been assumed that the interest of the reader in the discovery of a principle or fact will not be lessened by a little knowledge of the personality of the discoverer, especially when his name has become a part of the nomenclature of the science. The literature of electricity is now so extensive, that it would be difficult to enumerate the sources from which the writer has drawn in the preparation of this volume. In many instances original memoirs have been consulted, and where direct quotations are made that fact is indicated.

It is with great reluctance that the author consents to add another to the already large number of so-called "popular" books on electricity; but he believes that the treatment of a subject like this will not necessarily be unscientific or inaccurate because it is couched in language nearly free from technical terms and mathematical formulæ. That it must be less complete and exhaustive goes without saying; but the design of the author, as already intimated, is to present a sketch. Any reader who is so disposed will have no difficulty in finding material for filling in the details with any desired degree of elaboration.

T. C. M.

WASHINGTON, D. C., *May* 16, 1886.

PREFACE TO REVISED EDITION.

I HAVE taken the opportunity afforded by a reissue of this work, as the first in the Riverside Science Series, to add a Postscript, bringing the subject more or less to date, and to make a slight correction in the original text. My attention has been called to two errors only, and it happens that both were copied from original sources. One is in the cut on page 177, showing the skeleton Gramme Armature, in which the wire surrounding the S pole of the field magnet is coiled in the wrong direction. It was so in the cut from which this was copied, which was not sufficiently scrutinized before its adoption. The proper alteration in the cut is made in the present edition.

The other is of much greater interest, and will be found in the statement of the law of electro-magnetic induction at the foot of page 159. It is here stated that, when an electric current is passed through one of two parallel wires, it causes at first a current in the *same* direction in the other, while the fact is that the direction of the current is opposite to that in the inducing wire. Such an error in the statement of one of the most familiar principles of the science might easily be attributed to a *lapsus calami*, followed by careless proof-reading. In this instance, however, the principle is given, as stated in the text, in Faraday's own words, and, curiously enough, the distinguished discoverer committed the blunder himself, in communicating the result of his magnificent research to his friend Phillips, in a letter dated at Brighton, November 29, 1831; at least, it is so printed in Dr. Bence Jones's "Life of Faraday," from which the statement was copied without a thought as to its correctness.

T. C. M.

WASHINGTON, D. C., *March* 7, 1890.

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The Riverside Science Series

VOLUME I.

A CENTURY OF ELECTRICITY

By T. C. MENDENHALL

France, and *Germany* are to be drank in *electrified bumpers*,[1] under the diſcharge of guns from the *electrical battery.*

On the Fourth of July, 1885, at a few minutes past 5 o'clock, P. M., the President of the United States, at the Executive Mansion in Washington, received the following message, dated "at the dinner-table in London, 10.10 P. M.," of the same day: —

TO HIS EXCELLENCY THE PRESIDENT OF THE UNITED STATES, *Washington.*

A party of American citizens and of English friends of the United States have assembled at my table to celebrate the declaration of American independence, and to meet Mr. Phelps, the American minister, at dinner. We have just drunk your health, and wish you a long, happy, and prosperous life and a successful administration of your high office.

After giving the names of the distinguished gentlemen present, the message concludes: —

On this memorable anniversary we all return heartfelt thanks to the Almighty God for the blessings he has vouchsafed to the American government and people. CYRUS W. FIELD.

The following answer reached its destination before the dinner was ended: —

---

[1] "An *electrified bumper* is a small thin glass tumbler, near filled with wine and electrified as the bottle. This when brought to the lips gives a shock, if the party be close shaved, and does not breathe on the liquor." — FRANKLIN.

Executive Mansion, Washington, D. C.,
July 4.

To Cyrus W. Field, *Esq., London, England.*

I receive with heartfelt gratitude the kind sentiments expressed by you and your assembled guests. I am exceedingly pleased to know that the hearts of our citizens now in your company turn homeward with patriotic warmth while they celebrate the anniversary of American independence, and that, as they return thanks for all that God has done for us, they are joined by kind friends, who, though illustrating the greatness of another nation, can heartily rejoice in the success and prosperity of our government and people. Grover Cleveland.

When Franklin stretched his slender wire across the Schuylkill, the "Fourth of July" had no special significance, and, although chagrined that he had as yet been unable to bring anything out of his experiments of use to mankind, he was probably as far from anticipating the possibility of such an interchange of congratulations during the progress of a dinner as he was from foreseeing the events which gave rise to such an occasion.

Curiously enough, he was destined to play an important part in the stirring events of the succeeding half-century — events which, in the language of John Bright, made the day whose anniversary was thus celebrated, "a day of grief and humiliation to the multitudes in England, and a day of exaltation and joy to the multitude on the other side of the Atlantic;" and events of a more peaceful character, which helped to make possible the brilliant discoveries through which the two nations were afterwards united, by a bond affording practically instantaneous interchange of thought.

The history of the advancement of science shows that its progress has not lacked continuity. No one man, or no generation of men, can be justly credited with all that is involved in any one of the great inventions or memorable discoveries with which science has enriched the world. All have built upon the labors of their predecessors, and to understand the completed work it is necessary to know something of the history of its various stages. A river is not best understood by an examination of its mouth alone, but rather by tracing its sources and its tributaries. So, in attempting to become acquainted with the principles upon which the practice of the electricity of to-day is founded, it will be desirable to review briefly the early progress of the science, and to trace therein the germs of discoveries and inventions, that, within less than half a century, have well-nigh revolutionized business methods and social life.

Electricity, through its etymology at least, traces its lineage back to Homeric times. In the Odyssey reference is made to the "necklace hung with bits of amber" presented by the Phœnician traders to the Queen of Syra. Amber was highly prized by the ancients, having been extensively used as an ornamental gem, and many curious theories were suggested as to its origin. Some of these, although mythical, were singularly near the truth, and it is an interesting coincidence that in the well-known myth concerning the ill-fated and rash youth who so narrowly escaped wrecking the solar chariot and the terrestrial sphere, amber, the first known source of electricity, and the thunder-bolts of Jupiter are linked together. It is not unlikely that this substance was indebted, for some of the romance that clung to it through ages, to the fact that when rubbed it attracts light bodies. This property it was known to possess in the earliest times: it is the one single experiment in electricity which has come down to us from the remotest antiquity. Frequent references to it are to be found in many early writings, and among them is found the statement that workmen engaged in grinding and polishing amber for ornamental purposes were often seized with a violent tremor in their arms and bodies, — a greatly exaggerated account of what might have resulted from rubbing the substance. Twenty-five hundred years ago Thales, one of the "seven sages of Greece," knew of it. Descended from the Phœnician kings, he spent much of his life among the priests of Memphis, from whom he is thought to have derived his knowledge of this peculiar property of the substance. True to human instincts, he also undertook to construct a theory by which to account for it.

The power of certain fishes, notably what is known as the "torpedo," to produce electricity, was known at an early period, and was commented on by Pliny and Aristotle. Its effect in the human body was recognized, and it was thought that some individuals were capable of emitting electric sparks and flames. The possible value of electricity as a remedial agent was recognized in these early days, and then, as now, most extraordinary accounts of cures effected by its application were current.

But throughout all of these centuries, up to the sixteenth, there seems to have been no attempt to study electrical phenomena in a really scientific manner. Isolated facts which almost thrust themselves upon observers, were noted, and, in common with a host of other natural phenomena, were permitted to stand alone, with no attempt at classification, generalization, or examination through experiment.

Electricity as a science is, almost above all others, dependent for its development upon experiment. Naturally, then, it was obliged to await the awakening of the human understanding to the supreme importance of experimental and inductive methods, which constitute the "great glory and distinction of modern philosophy." This occurred at the close of the sixteenth century, and it is commonly assumed that it was left for a distinguished lawyer and profound jurist to reveal to philosophers the true principles of philosophy.

Almost contemporaneous with Bacon lived William Gilbert, of Colchester, first physician to Queen Elizabeth, and one of the most extraordinary men of his time. In the preface to his great work, "De Magnete," he denounces in vigorous terms the methods of "philosophizing" then in vogue, expressing sentiments and using language strikingly similar to those of Lord Bacon. His work is often referred to as the "first-fruits of the Baconian or experimental philosophy;" but Gilbert died when Bacon was barely thirty years of age, and long before the publication of the "Novum Organum." Dr. Gilbert can justly be called the creator of the science of electricity and magnetism. His experiments were prodigious in number, and many of his conclusions were correct and lasting. To him we are indebted for the name "electricity," which he bestowed upon the power or property which amber exhibited in attracting light bodies, borrowing the name from the substance itself, in order to define one of its attributes. He constructed a real electroscope, consisting of a light needle resting on a point, and by its use discovered that the power of attracting light bodies did not belong to amber alone, but that it was possessed by many other substances when they were properly excited. He examined into the conditions favorable or unfavorable to the production of electrical phenomena, and discovered the influence of a moist or a dry atmosphere.

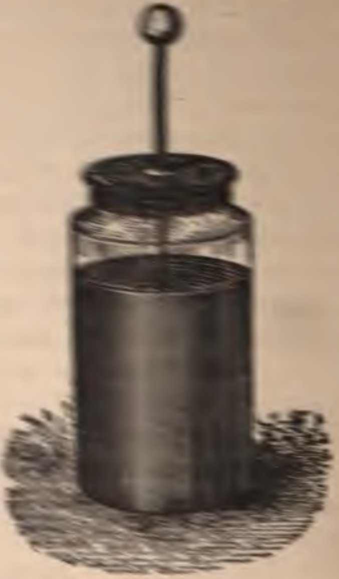
This application of experiment to the study of electricity, begun by Gilbert three hundred years ago, was industriously pursued by those who came after him, and the next two centuries witnessed a rapid development of the science. Among the earlier students of this period were the English philosopher, Robert Boyle, and the celebrated burgomaster of Magdeburg, Otto von Guericke. The latter first noted the sound
' light accompanying electrical excitation.
e were afterwards independently discov-
by Dr. Wall, an Englishman, who made

the somewhat prophetic observation, "This light and crackling seems in some degree to represent thunder and lightning." Sir Isaac Newton made a few experiments in electricity, which he exhibited to the Royal Society. He did not, however, allow his interest in them to divert his attention from his other studies, although he made electricity the subject of several of his famous "Queries." Francis Hawksbee was an active and useful contributor to experimental investigation, and he also called attention to the resemblance between the electric spark and lightning.

The most ardent student of electricity in the early years of the eighteenth century was Stephen Gray. He performed a multitude of experiments, nearly all of which added something to the rapidly accumulating stock of knowledge, but doubtless his most important contribution was his discovery of the distinction between conductors and non-conductors. In endeavoring to see how far the "electric virtue," as he termed it, could be carried or transmitted, he had at first confined himself to its transmission in a vertical direction by means of suspended cords, rods, etc. The available distance in this direction being limited, he undertook to use horizontal lines of transmission, in which he sometimes succeeded and sometimes failed. He finally supported his lines by means of silk thread, by which means he was more successful than with other supports, "on account of its smallness," as he thought and declared. On one occasion the silk thread broke under the weight of his long line, and he substituted a metal wire, when, to his surprise, he was unable to produce the slightest electrical effect at the distant end. He was at once led to believe that the "virtue" had leaked out through the metal, and that the smallness of the silk was not the reason of its effectiveness. The division of bodies into conductors and non-conductors, arising out of this experiment, constituted a decided advance for both theory and practice. Gray also prepared two oak blocks, one solid and the other hollow, and by experimenting upon them found that the hollow block was electrified as easily and as strongly as the other. He electrified a soap-bubble, and also a boy who was suspended by hair ropes, and found that the human body was capable of exhibiting electrical phenomena.

Some of Gray's papers fell into the hands of Dufay, an officer of the French army, who, after several years' service, had resigned his post to devote himself to scientific pursuits. He repeated many of the experiments described by the Englishman, and became an enthusiastic student of the science. His work shows great acuteness of mind, as well as remarkable experimental skill. He made a critical examination of a curious experiment made by Gray, in which it appeared that the color of bodies influenced their susceptibility to electrical disturbance. His observations at first seemed to confirm the conclusion reached by Gray; but he possessed the ingenuity to devise a crucial test, which consisted in arranging a number of pieces of the same cloth, originally white, but made to appear of different colors by throwing different parts of a prismatic spectrum upon them. He found that they then exhibited no differences, and afterward proved that such variations as had appeared were to be attributed to the coloring-matter employed in the process of manufacture. His most important discovery was the existence of two distinct species of electricity, which he named "vitreous" and "resinous;" the first being applied to that which exists on glass when it is rubbed, and the second to that of amber and other resinous substances. In this observation he anticipated Mr. Kinnersley, who was the friend and associate of Franklin; but Kinnersley immediately recognized, what Dufay had failed to see, the identity of these two electricities with Dr. Franklin's positive and negative charges.

A very important advance was made in 1745 in the invention of the Leyden jar or phial.[1]



Leyden Jar.

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[1] A Leyden jar, as usually made, consists of a glass jar (one having a wide mouth is most conveniently prepared), coated with tinfoil, within and without, to within a few inches of the top. The mouth is generally closed by a disk of dry wood, through which passes a wire reaching to the inner coating. The outer end of the wire usually terminates in a small metallic ball. Its essential feature is that it consists of two conducting surfaces, separated by a non-conductor; and in the phial, as first used by Muschenbroeck, the inner conductor was water, the place of the outer being taken by the moist hand of the experimenter. It is "charged" by connecting either coating with the source of electricity, while the other is connected with the earth.

As has so many times happened in the history of scientific discovery, it seems tolerably certain that this interesting device was hit upon by at least three persons, working independently of each other. One Cuneus, a monk named Kleist, and Professor Muschenbroeck, of Leyden, are all accredited with the discovery; but the name of the city in which it was earliest exhibited and experimented with is that by which it has ever since been known. By its use, electricians were immediately able to work upon the mysterious "virtue" or "effluvia" in larger quantities, and to produce effects entirely unknown before. Sir William Watson perfected it by adding the outside metallic coating, and was by its aid enabled to fire gunpowder and other inflammables. In company with a number of Fellows of the Royal Society, he used it in making experiments upon the velocity with which electricity was transmitted through metallic conductors. They succeeded in sending it through a wire more than twelve thousand feet in length, and reached the conclusion, that, so far as they were able to determine, its transmission was instantaneous.

About the beginning of the year 1747, Peter Collinson, of London, a Fellow of the Royal Society, sent to his friend Benjamin Franklin, in Philadelphia, what the latter called an "electrical tube," with instructions for using it. Soon after receiving it, Franklin began a series of experiments, resulting in discoveries "the extent and brilliancy of which," according to a celebrated English authority, "gave a form and dignity to the science of electricity which it had never before possessed, and raised their author to a high rank among the distinguished philosophers of the eighteenth century." On March 28, 1747, he wrote to Mr. Collinson, saying, "For my own part, I never was before engaged in any study that so totally engrossed my attention and my time, for what with making experiments when I can be alone, and repeating them to my friends and acquaintance, who, from the novelty of the thing, come continually in crowds to see them, I have, during some months past, had little leisure for anything else."

The results of and deductions from these experiments were communicated to Mr. Collinson in letters transmitted to him from time to time. These were read to the Royal Society, but they did not at first meet with a cordial reception. Some were laughed at, and none were thought worthy of publication in the Transactions of the Society until electricians in other countries, and notably in France, had repeated the experiments, and acknowledged the genius of their author. They were, however, published in London, and, at the instigation of Buffon, translated into French; in which language they met with a juster appreciation than in the English, in which they were written. The Royal Society was soon obliged to retrace its steps in the matter; and in the Transactions for 1751 appears a fair and favorable account of Franklin's experiments up to that time, prepared by Sir William Watson. In the way of making the *amende honorable*, this account concludes as follows: —

> On the whole, Mr. Franklin appears in this work in the light of a very able and ingenions man; that he had a head to conceive and a hand to carry into execution whatever he thought might conduce to enlighten the subject of which he was treating; and though there are in this work some few opinions in which Mr. W. could not perfectly agree with him, he thought *scarcely any body was better acquainted with the subject of electricity than Mr. F. was.*

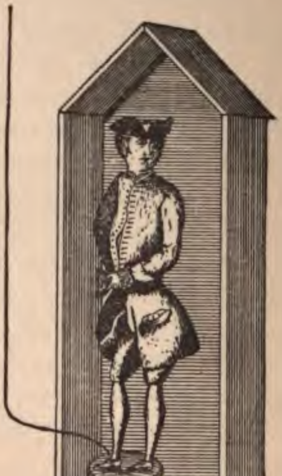
In justice to the society it ought to be added, that, on the occasion of his visit to Europe in 1755, Franklin was received by its members with every honor, was elected a fellow, the payment of dues being remitted, the great Copley medal was bestowed upon him, and the Transactions of the Society were sent to him without expense during the remainder of his life.

Franklin's contributions to the science of electricity were numerous and comprehensive. His experiments were wisely planned and skilfully executed. His discussion of principles and his elaboration of hypotheses were characterized by that simplicity and clearness which made his writings upon all subjects the admiration of his own and future generations. He was the first who made an investigation of the Leyden jar which was at all satisfactory. In experimental work he improved both methods and instruments. The discovery which gave him the greatest fame was that of the identity of lightning and electricity; and his immediate use of the known laws of electricity, principally those of which he was himself the discoverer, in the invention of means for protecting buildings from damage by lightning, stands singular and alone as the only really useful application to the affairs of every-day life of centuries of study and experiment. The germ of this discovery seems to have existed in his mind during the year 1749; and under date of November 7 of that year the following passages occur in his note-book: —

Electrical fluid agrees with lightning in these particulars: 1. Giving light. 2. Color of the light. 3. Crooked direction. 4. Swift motion. 5. Being conducted by metals. 6. Crack or noise in exploding. 7. Subsisting in water or ice. 8. Rending bodies it passes through. 9. Destroying animals. 10. Melting metals. 11. Firing inflammable substances. 12. Sulphureous smell. The electric fluid is attracted by points, — we do not know whether this property is in lightning. But since they agree in all the particulars wherein we can already compare them, is it not probable they agree likewise in this? *Let the experiment be made.*

Shortly after this, the hypothesis was elaborated and communicated to his friend Mr. Collinson. This account of it reached France in the manner already described, where it attracted much attention. It is not generally known that his suggested experiment of drawing electricity from the clouds was not first tried by himself, but by Monsieur D'Alibard at Marly on May 10, 1752. A few days later it was successfully repeated by M. de Lor in Paris. The results of these trials were communicated to the Royal Society by Mazeas, who added, that the "Philadelphian experiments were so universally admired that the King himself desired to see them." They became the sensation of the time, and were repeated wherever electricity was studied."

Franklin's original plan for drawing electricity from the clouds was to place a man in a sort of sentry-box, insulating him by means of a cake of wax, and putting him in connection with an iron rod which extended many feet into the air. If the experiment succeeded, sparks might be drawn from the man. He did not appear to think that the person thus experimented upon might possibly be in danger; but, suspecting that some might be apprehended, he afterward suggested slight modifications in the experiment, to secure his safety. The arrangement which he proposed is shown in the cut,



Method of drawing electricity from the clouds suggested by Franklin. Enlarged from cut accompanying his original paper.

which is an enlargement of that accompanying his original published paper. Franklin himself afterward performed the experiment by means of a kite, a description of which he transmitted to the Royal Society under date of October 19, 1752, in which he modestly relates an experience which was destined to enjoy a lasting fame.

Among the cultivators of the science of electricity during this period, the distinguished German philosopher, Æpinus, must be mentioned, as well as the equally distinguished Englishman, Henry Cavendish. The latter was the first to make accurate experiments upon the relative conducting powers of different substances, and also the first to study the chemical effects of electricity, which were afterwards to grow into such importance. He exploded mixtures of oxygen and hydrogen by means of the electric spark, and, by varying the proportions, obtained such a combination that nothing but water was the result, thus proving the composition of this substance.

Finally, reference must be made to the work of one of the ablest experimental philosophers of the age, Charles Augustin Coulomb. To him the science is indebted for the discovery and proof of the law of electric attraction and repulsion. By means of a series of experiments exhibiting marvellous skill and ingenuity, he showed that the force exerted was, as Newton had found the attraction of gravitation, inversely proportional to the square of the distance. The methods he devised were of such value that many of them are still employed in the most precise quantitative researches.

From this brief and inadequate review it is hoped that the reader may be able to form a fairly correct estimate of the amount and value of the development of the science up to the beginning of the present century. It will be seen that great activity prevailed during the eighteenth century, and that the stock of accumulated knowledge was enormously greater than all that had existed prior to the time of Gilbert. But the student of the electricity of Gilbert, Gray, Franklin, and Coulomb, cannot fail to note that their knowledge was still in a great degree unclassified, and hence unscientific. It consisted largely of a considerable collection of experiments, often brilliant and ingenious, often isolated and unrelated, and was far from being the compact, orderly, and almost exact science of to-day. Aside from Franklin's lightning-rod, it contributed nothing of practical value to the people at large.

The mysterious nature and behavior of the "electric virtue," however, had inspired many, even among scientific men, with the belief that it was destined to be of great service as a medicinal agent. Almost from the beginning of its experimental study, the most marvellous and extravagant accounts of its curative powers were spread abroad. The Italian and German philosophers seemed to be the most successful in its application; and their narratives of cures and other performances were so extraordinary, that the Abbé Nollet, after having himself failed in all his attempts to imitate them, undertook a tour to Italy and elsewhere with the express purpose of learning the exact conditions necessary to success. One of these experiments, that attracted great attention for a time, was that known as the "beatification." It consisted in an electrification of the human body such that "the man's head is surrounded by a glory, such a one in some measure as is represented by painters in their ornamenting the heads of saints." It was supposed to be accomplished by the use of electrified globes or bottles; and Professor Boze, the author of the experiment, discourses ingenuously upon the fact that one man may be beatified and another may not, and that, while sometimes a man will be beatified by one globe in two minutes, at another five or six globes will fail altogether in bringing it about. All of these marvellous stories were rigidly investigated by Nollet, and it is hardly necessary to say that they were found to be entirely without foundation. Had Franklin's "electrified bumpers" been made use of, the "beatification" experiment might have been more generally successful.

Franklin, who had experimented upon the effect of electricity on animals, and had generally succeeded in killing his subject, appears to have had little faith in its medicinal use. He speaks of its having been imagined in America that deafness could be relieved by its use, and, concerning a proposal to apply it to the eyes "to restore dimness of sight," he remarks that "it will be well if perfect blindness be not the consequence of the experiment." He also refers to the danger likely to arise in its indiscriminate use by people who do not understand its effects.

The golden age is, always was, and doubtless always will be, the present; yet it would seem that, without any loss of dignity, the present might learn from the mistakes of the past, and transmute its foolishness into wisdom. The advertising columns of the periodicals of the present time furnish incontestable evidence, however, of the fact that the people of to-day welcome mystery and deception, if not recognized fraud, just as readily and with as much self-satisfaction as did their ancestors of a hundred years ago.

Very near the close of the eighteenth century an Italian philosopher made an observation so new and so novel that it at once set the electricians upon a new track. It was the beginning of what may be called the New Electricity, and, as its development practically began with the new century, its consideration will be deferred until the next chapter.

CHAPTER II.

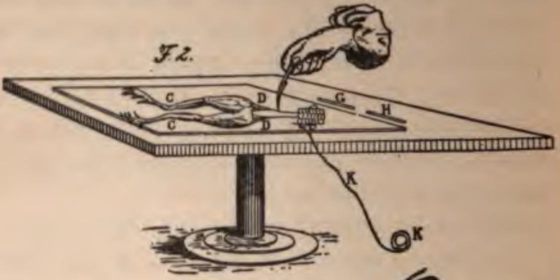
GALVANI, VOLTA, THE BATTERY AND THE ELECTRIC CURRENT.

THE world will perhaps never know with certainty to what extent it is indebted to a woman for the inauguration of the new era in electrical experiment and research. A hundred years ago, September 20, 1786, Galvani, an Italian physician, saw, in the twitching of the legs of a frog, the beginning of modern electricity. It is difficult to understand how the circumstances attending so important a discovery should in any way be involved in obscurity, but, nevertheless, such is the case. Several high authorities, including the eulogist of Galvani, M. Alibert, have given weight to the pleasant story in which it is related that the wife of the philosopher, being in a declining state of health, "employed as a restorative, according to the custom of the country, a soup made of frogs." The culinary and philosophical operations of Galvani's establishment not being completely differentiated, several of these animals, after being prepared for the former, were placed on a table on which the latter was represented by an electrical machine. While the machine was in operation, one of the frogs was accidentally touched by a knife in the hands of an assistant, and the muscles of the limb were instantly thrown into strong convulsions. This fact was observed by the lady, who communicated it to her husband on his return.

The editor of Galvani's works, published in 1841 by the Academy of Sciences of the Institute of Bologna, Sylvestro Gherardi, discredits this story entirely, and indignantly labors to put a quietus upon it, although he quaintly adds in a foot-note: "In this connection we do not wish to deny that Galvani might not, on one or more occasions, have had frogs in his hands with the amiable intention of himself preparing broth for his adored spouse." Galvani's own account of the experiment is contained in the opening paragraph of his work, "De Viribus Electricitatis Artificialis in Motu Musculari," and is essentially as follows: —

> I dissected a frog, and prepared it as in Fig. 2, Plate V., and, putting it on the table on which was the electrical machine (Fig. 1) I placed it wholly disconnected from its conductor, and separated from it by an interval not short. One of those who were assisting me in the work lightly touched by accident,

with the point of the scalpel, the internal nerves *D D* in the legs of the frog, when all at once every muscle



Luigi Galvani

Galvani's Fig. 2, Plate V., with autograph.

of the joints was seen to be contracted, so that they seemed to have fallen into the most vehement and violent convulsions.

It appears to be tolerably well established that Galvani was long engaged in the investigation of the effect of electricity upon the muscles of animals, and that he gave especial attention to its influence upon the frog, which, owing to its extreme sensitiveness to electric disturbances, was well calculated to be the means of leading him to the discovery which has forever fixed his name in the nomenclature of the science. It seems that some of these animals were suspended on an iron railing by means of copper hooks, and that their muscles occasionally twitched when there was no apparent electrical disturbance in their vicinity. This was the observation of prime importance, and it is recorded as having been made on the date mentioned above. It did not become generally known, however, until about 1790, when it immediately attracted the attention of students of electricity in all countries.

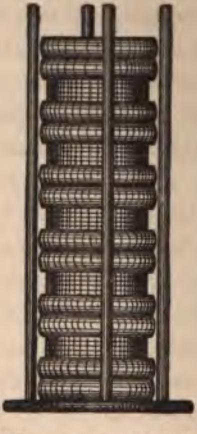
Galvani believed that the animal was itself the source of the electricity, and that the connecting pieces of metal acted only as conductors. Thus arose the term "Animal Electricity;" and by many who doubted the identity of the new and the old the word "galvanism" was used,— a name which held its place so tenaciously that it has been only recently dislodged.

Among those who took a deep interest in Galvani's discovery was another Italian philosopher who was destined almost to wrest from his countryman the honor of having created a new science. Although descended from an ancient and honorable family, Volta exhibited in his youth a very slow development of intellectual powers, — a fact ascribed by his friends to his having been placed in the care of a foolish nurse. His earliest exhibition of talent was in making poetry, from which he easily and rapidly rose to a position of great distinction as a man of science, and he especially cultivated the science of electricity. Galvani's discovery found him in the prime of life, well trained for observation and experiment; and, indeed, he had already made some notable contributions to the knowledge of electricity then existing.

In 1793 he communicated to the Royal Society of London an account of some discoveries made by M. Galvani, to which he added many curious and valuable observations of his own. He did not agree with Galvani in the view held by the latter as to the origin of the new electricity. He found that two different metals were essential to the successful performance of the experiment with the frogs' legs, and he attributed the appearance of electricity to the disturbance of the electric equilibrium brought about by the contact of the two different metals. He enunciated the general proposition, that, whenever two different metals are placed in contact, one will become positively and the other negatively charged. This was the first statement of what is known as the "contact theory" of the voltaic cell, and to this theory Volta clung persistently.

Later on, when the chemical action of the voltaic current came to be studied, and especially when the chemical action going on in the cell came to be understood, what is known as the "chemical theory" was advocated, in which the seat of the electromotive force of the cell was affirmed to be in the chemical affinity existing between its elements. The advocates of this theory generally denied that any electrical separation or disturbance of electric equilibrium took place on the contact of two dissimilar metals. The conflict between these two hypotheses has continued, with intermittent vigor, from that day to the present. Strong arguments in favor of the chemical theory have been furnished by Faraday, De La Rive, Becquerel, and others, while Volta has been sustained by Sir William Thomson and several eminent electricians of continental Europe. Although the subject has received much attention from the ablest authorities of the present century, it seems safe to say that the real seat of the electromotive force of a voltaic battery is not yet known.

The battery, or "pile," was Volta's great contribution to the science. For many years it afforded the only means of generating electricity in considerable and manageable quantities. By its use many of the most remarkable discoveries were made. In various forms its practical applications have become so extensive and so common, that it is probably the best known of all electrical instruments. Its invention evidently came to Volta through his reflections upon the contact theory. Believing that electrical separation takes place when two dissimilar metals come in contact, he thought to magnify the effect of a single pair by increasing the number. Pairs of dissimilar metals of like dimensions were bound together by placing a thin, moist substance between consecutive pairs. Disks of metal, consisting of silver coins and pieces of zinc, and moistened paper, were used, and, when put together, the pile was formed as shown in the figure. When this was done, he found it no longer necessary to use so sensitive



Volta's pile. Copied from a cut published early in the present century.

an electroscope as the legs of a frog to detect the electrification. He could himself feel the shock it produced on touching the opposite extremities of the pile, and immediately convinced himself of the identity of electricity and the so-called galvanism. All of the characteristic effects of electricity as produced by friction upon glass, sulphur, and other substances, could be shown by the new instrument. He transmitted an account of his discovery to the Royal Society of London in a letter to Sir Joseph Banks; it soon became widely known, and was the sensation of the time in scientific circles, and, indeed, everywhere.

It is interesting to note how nearly an Englishman, Professor Robinson, came to hitting upon the same invention, in noticing a peculiar sensation of taste which is excited by touching the tongue upon the edges of a number of plates of silver and zinc when placed alternately upon each other, — an observation which he made and published before the date of Volta's discovery. Volta modified the form of his apparatus by placing the two dissimilar metals in cups of water, and then joining them together by metallic conductors, thus putting his battery in a shape which it has retained, practically, to the present day. But he seems to have reaped very little of the harvest which was from that time in store for the cultivators of electricity. His principal interest was in the vindication and establishment of his contact theory, to which task he devoted himself almost exclusively for the remainder of his days.

After the invention of the battery, and beginning with this century, the progress of the science was extremely rapid. A series of brilliant discoveries followed within a few years, which at that time were as notable, and many of them as far-reaching, as those more recent. One of the earliest and most important of these, because it opened up an entirely new field of research, was the decomposition of water by means of the battery, — an experiment first made by two Englishmen, Messrs. Nicholson and Carlisle. It formed the groundwork of nearly all that was accomplished during the first twenty years of the century, and is worth describing in Mr. Nicholson's own words. He says: —

> On the 2d of May (1800) we inserted a brass wire through each of two corks inserted in a glass tube of half an inch internal diameter. The tube was filled with new river-water, and the distance between the points of the wires in the water was one inch and three quarters. This compound discharger was applied so that the external ends of its wire were in contact with the two extreme plates of a pile

of thirty-six half-crowns, with the corresponding pieces of zinc and pasteboard. A fine stream of minute bubbles immediately began to flow from the point of the lower wire in the tube which communicated with the silver, and the opposite point of the upper wire became tarnished, first deep orange, and then black. On reversing the tube, the gas came from the other point, which was now lowest, while the upper in its turn became tarnished and black. . . . The products of gas during two hours and a half was two thirtieths of a cubic inch. It was then mixed with an equal quantity of common air, and exploded by the application of a lighted waxen thread.

Platinum was used instead of the brass wires, and gas was liberated at both poles. When collected separately and examined, one proved to be hydrogen, and the other oxygen. Other experimenters substituted salts of copper and lead for the water, and found in each case that the pure metal was deposited at one of the poles. These were the beginnings of electro-chemistry.

Among the many who became interested in the new science was a young Englishman named Davy. He was a man of marked ability and varied attainments. Coleridge described him as "the individual who would have established himself in the first rank of England's living poets, if the genius of our country had not decreed that he should rather be the first in the first rank of its philosophers and scientific benefactors." Appointed experimental chemist of the Royal Institution, London, in 1801, he immediately began a series of splendid discoveries which did much to establish the fame of the institution, founded a little earlier by Count Rumford, and which made the name of Sir Humphry Davy more widely known than that of any other scientific man of the age.

Davy studied the theory and operation of the pile, but the major part of his important discoveries were really contributions to chemistry, made possible by the use of the electric current. They were based upon a most valuable observation by Hisinger and Berzelius, who noted, that, when the current decomposed a neutral salt or an oxide, the oxygen and acid were carried to the positive pole, and the base to the negative.

In this connection it is important to notice, that, in the earlier construction of the pile or battery, Volta's contact theory was strictly exemplified. In putting the plates together, the order — copper, zinc, fluid; copper, zinc, fluid; and so on — was adhered to, the series beginning with copper and zinc, and ending with the same. Erman of Berlin pointed out that the presence of the copper at the beginning, and the zinc at the end, might be dispensed with, and that it was proper to say that the zinc end was the negative pole, and the copper end the positive. The same observation was made by Dr. Priestley, who at this time was experimenting in America. This explanation will account for an apparent error in Nicholson's description of his experiment, already quoted.

Davy saw in the voltaic battery a new and powerful means of producing decomposition. After experimenting extensively on already recognized compounds, he ventured to attack the so-called "fixed alkalies," whose composition was unknown. By greatly increasing the power of his batteries, and varying his arrangements in many ways, he was finally victorious. This famous experiment of October 6, 1807, he described as follows: —

> A small piece of pure potash which had been exposed for a few seconds to the atmosphere, so as to give conducting-power to the surface, was placed upon an insulated disk of platina, connected with the negative side of the battery, of the power of 250 of 6 and 4, in a state of intense activity; and a platina wire communicating with the positive side was brought into contact with the upper surface of the alkali. The whole apparatus was in the open atmosphere. Under these circumstances a vivid action was soon observed to take place. The potash began to fuse at

both its points of electrization. There was a violent effervescence at the upper surface: at the lower or negative surface there was no liberation of elastic fluid; but small globules, having a bright metallic lustre, and being precisely similar in visible characters to quicksilver, appeared, some of which burst with explosion and bright flame as soon as they were formed, and others remained and were merely tarnished, and finally covered by a white film which formed on their surfaces.

These small globules, with bright metallic lustre and resembling quicksilver, were globules of the metal base of potash, never before seen, and which Davy named "potassium." By a similar process sodium was obtained from soda; and with great rapidity barium, strontium, calcium, and magnesium followed, and other more refractory compounds were attacked and conquered.

These decompositions so successfully accomplished by Davy must ever be regarded as constituting an epoch in the history of physical science. They were not only brilliant in their own right, but rich in the promise which they gave of the value of the new electricity in chemical research. They were at once repeated and extended by the most eminent chemists of the day, and with such important results that for nearly twenty years almost the sole use of the electric current was for purposes of decomposition. But it was found to produce another effect, quite distinct from that referred to above, and calculated equally with that to attract the attention of the curious as well as to court investigation by the philosopher.

In the previous chapter frequent reference was made to the heating power of the older electricity, through which ignitions were brought about, metallic wires were melted, and so on. About the time that Davy was beginning his experiments, it was observed, probably first by Trommsdorff, that the voltaic current was capable of producing similar effects. The first experiment was made by attaching a piece of gold-leaf to one pole of the battery, and touching it with a wire connected to the other. The gold-leaf was rapidly consumed, producing beautifully colored flames. By improvements in the form of the battery, and especially by increasing its dimensions, very powerful heating effects were produced: long wires of iron, platinum, and other refractory substances, were fused. An experiment suggested by Dr. Wollaston gave a result which was at that time extremely curious, but which will receive its full explanation later on. It was that a greater length of thick platinum wire was ignited than another of the same substance but much smaller in diameter. Davy did not neglect this heating power of the battery, and it is affirmed that he produced the electric light from carbon on a small scale as early as 1802. The remarkable discoveries which he had succeeded in making by the use of his battery of 250 cells produced such enthusiasm among all lovers and patrons of science, that he was enabled to continue his researches, assisted by one of the most powerful batteries ever constructed. It was erected in the Royal Institution, and consisted of 2,000 cells, with a total surface of 128,000 square inches. The metals of this battery were copper and zinc, and the liquid was a mixture of water, and nitric and sulphuric acids. When it was put in action the effects were extraordinary. They are described by Davy as follows: —

> When pieces of charcoal about an inch long and one sixth of an inch in diameter were brought near each other (within the thirtieth or fortieth of an inch), a bright spark was produced, and more than half the volume of the charcoal became ignited to whiteness; and, by withdrawing the points from each other, a constant discharge took place through the heated air, in a space equal to at least four inches, producing a most brilliant ascending arch of light, broad and conical in form in the middle. When any substance was introduced into this arch, it instantly became ignited; platina melted as readily in it as

wax in a common candle; quartz, the sapphire, magnesia, lime. all entered into fusion; fragments of diamond and points of charcoal and plumbago rapidly disappeared and seemed to evaporate in it, even when the connection was made in a receiver exhausted by the air-pump; but there was no evidence of their having previously undergone fusion. When the communication between the points positively and negatively electrified was made in the air rarefied in the receiver of the air-pump, the distance at which the discharge took place increased as the exhaustion was made; and, when the atmosphere in the vessel supported only one fourth of an inch of mercury in the barometrical gauge, the sparks passed through a space of nearly half an inch; and, by withdrawing the points from each other, the discharge was made through six or seven inches, producing a most brilliant coruscation of purple light; the charcoal became intensely ignited, and some platina wire attached to it fused with brilliant scintillations, and fell in large globules upon the plate of the pump. All the phenomena of chemical decomposition were produced with intense rapidity by this combination. When the points of charcoal were brought near each other in non-conducting fluids, such as oils, ether, and oxymuriatic compounds, brilliant sparks occurred, and electric matter was rapidly generated; and such was the intensity of the electricity that sparks were produced, even in good imperfect conductors, such as the nitric and sulphuric acids. When the two conductors from the ends of the combination were connected with a Leyden battery, one with the internal, the other with the external coating, the battery instantly became charged, and on removing the wires and making the proper connections, either a shock or a spark could be perceived; and the least possible time of contact was sufficient to renew the charge to its full intensity.

This celebrated experiment, made before members of the Royal Institution in 1810, was the first production and exhibition of the electric current and the electric light on a large scale. It is easy to conceive how public expectation must have been excited by such a result, but more than half a century elapsed before these expectations could be realized.

Davy's apparatus consisted essentially of two parts, — the battery, for the production of electricity; and the lamp or carbon rods, for converting the energy of the current into heat and light. The battery was as described; and the lamp, if such it may be called, consisted, according to his own account, of two rods of common charcoal. The system was weak and imperfect in both of its elements; and many years, filled with the labor of many men, were necessary to bring it to anything like perfection. Although the germ of success was in it, it does not appear that any special effort to develop it was made for a long time. So many problems of interest were constantly presenting themselves to students of electricity that they were not tempted to turn aside to consider its practical applications; and, indeed, the materials for the complete solution of the problem of lighting by electricity were not yet at hand.

In the mean time improvements in the form and construction of the battery were being made, in response to constant demands. As long as it retained the construction substantially given to it by Volta, consisting of a single liquid or mixture of liquids in which two metals were immersed, it possessed certain grave faults which rendered its use extremely inconvenient. In order to understand the nature of these faults, as well as the remedies that have been successfully applied, it will be desirable to consider somewhat thoroughly a few points in regard to the action of a battery.

Some very interesting observations on this action were made shortly after the discovery of the pile. In the earlier forms a large number of pairs were used, and, as already related, the physiological effects produced by touching the poles were similar to those of what was then known as "common" electricity. Experiment proved that the so-called "galvanism" was similar to this electricity in many other respects: it produced divergence in the leaves of a gold-leaf electroscope; Leyden jars were charged by it; sparks were produced by it; in short, it seemed clear that the two extremities of the pile or battery were in opposite states of electrification, one being positive and the other negative, and that they acted as any other oppositely electrified bodies would act. The battery, however, differed remarkably in two respects from all previously known devices for producing electricity. In the first place, the difference in the electrification of the two poles was extremely feeble; that is to say, the difference in the electrical states of a glass rod and a bit of silk, after a few strokes of the one on the other, is several thousand times greater than that of the two poles of a single battery-cell. It was soon discovered that this "polar difference," or intensity of electrification in a battery, depended on the number of pairs or cells, and not at all on their size. As most of the effects of the pile first studied depended almost entirely on this "intensity of electrification," it was naturally found that small plates were just as satisfactory as large ones, "provided, only, that their number was sufficient;" and it was also observed that the results depended on the metals used for these plates rather than on the nature of the liquid in which they were immersed.

To this difference in the electrification of the two poles of a cell the term "electromotive force" is applied to-day; it is also frequently spoken of as the "difference of potential" between the poles. As already stated it depends almost entirely on the character of the poles or electrodes, not at all on their dimensions, and not to a very great extent on the nature of the liquid in which they are plunged. Whatever may be its real origin, to it must be attributed the movement or flow of electricity in the completed circuit. It has been likened many times to the pressure of a "head" of water, by means of which it is forced through a system of pipes; and in this case it is well known that the pressure does not depend upon the quantity of water, or the cross-section of the pipe in which it stands, but alone on the height at which it is maintained.

Electromotive force is one of the two things upon which depends the action of an electric circuit. A Leyden jar, when charged, possesses electromotive force, the inside and the outside coating differing in "potential" by an amount generally enormously greater than the poles of a battery-cell. But, in spite of its relative weakness in this respect, the latter has advantages over the former in another which are so immense as to at once establish its superiority as a useful instrument. If the two poles of a Leyden jar (the inside and outside coatings) be joined by a conductor, an electric current is set up, and the jar is discharged almost instantly, and is capable of nothing more until it is recharged. If the poles of a battery be joined by a conductor, a current is established, in virtue of the existing electromotive force, as in the first instance; but now the current is maintained, and with constant strength, as long as the battery remains in its initial condition. Thus, by multiplying the number of cells, the electromotive force of the system can be made equal to that of the Leyden jar, and a current may be maintained for hours and for weeks. The energy of the current, supplied continually by the chemical action in the battery, may be utilized as heat, for the production of motion of matter at a distance, or through any of the numerous transformations of which it is susceptible.

In making use of the battery for the production of electric currents, it is found that the strength of the current, measured by the quantity of electricity which flows in a unit of time, depends upon another condition of the circuit quite as much as it does upon the electromotive force existing therein. Some of the earlier experiments pointed the way to an understanding of this question, but the hint was not taken at once, and for a long time it remained clouded in obscurity. Later on, some account will be given of the discovery of the beautiful and simple law which expresses the exact relation between the current strength in a circuit, its electromotive force, and its resistance. At present it will be necessary and sufficient to call attention in a general way to the principles involved.

The primary cause of the flow of the current is the electromotive force. If the two poles of a battery, or any two electrified bodies which differ in potential, be joined by a conductor, flow of electricity will take place, precisely as flow of water will occur if two reservoirs differing in height or head be connected by a pipe. The older electricians found that in discharging a Leyden jar, if an imperfect conductor, such as a moistened thread, were used, the operation required greater time and the strength of the current was correspondingly less; exactly as, in the case of the reservoirs, if the connecting pipe be small, or if for any other reason it offer considerable resistance, the quantity of water passing in a unit of time will be small. In other words, with a given electromotive force, the strength of the current will depend upon the resistance of the circuit, being inversely proportional to the same.

Now, it is important to observe that the battery itself forms a part of the circuit, and that the resistance which it offers to the passage of the current is just as important in determining the current strength as that of any other part of the circuit. Increasing the size of the plates diminishes the resistance of the cell, very much as an increase in the diameter of a pipe diminishes the resistance which it offers to water flowing through it. Decreasing the size of the plates has, of course, the contrary effect. Again: the liquids used in battery-cells differ widely in their conducting power, and the resistance of the battery will depend largely upon their character. In all cases, since the metal plates of the battery are almost incomparably superior as conductors to the liquids used, it will be easily seen that the resistance of the battery will be lessened by putting the plates nearer together in the liquid, so that the length of the latter to be traversed by the current shall be as small as possible.

Turning now to the consideration of the objections to the earlier forms of batteries, it will not be difficult to understand their origin, and how they have been overcome. An ideal battery should maintain a constant electromotive force through the whole time of its action; its resistance should be as low as possible; the materials of which it is constructed should be such as not to become rapidly changed in their character during its action, so that its life may be as long as possible; and there should be little or no chemical action going on when the circuit is broken, so that the energy of chemical change shall all be concerned in, or incident to, the production of the current. The first forms of battery, which were single-fluid batteries, failed to meet many of these requirements.

The following simple though instructive and striking experiment is well worth making by any one who desires to understand the principal difficulty in the way of meeting the first. Take a small glass tumbler, fill it two thirds full of water, and mix with it about one seventh of its bulk of sulphuric acid. Prepare a strip of zinc and a strip of copper, each somewhat longer than the depth of the tumbler, and well cleaned. Put them in the dilute acid so they are not in contact. Bubbles of gas will generally be seen to form about the zinc plate, some of which will rise to the surface. If the zinc be pure, little, if any, gas will appear, and the copper will be unaffected. Now incline them until they rest in contact at the top, or join their upper ends by a wire. This is Volta's cell in operation. Bubbles of gas now appear in considerable numbers about the copper plate.

In both cases the gas is hydrogen. When the metals touch at the top, an electric current passes from the copper to the zinc at the top, and from zinc to copper through the liquid. During the operation the zinc is being consumed: that is to say, it is being changed to sulphate of zinc by combining with the sulphuric acid. The copper is in no way altered, except that the bubbles of gas appear about it. That they appear there rather than at the zinc is the striking feature of the experiment; and it must be confessed, that, although it is a phenomenon which has constantly presented itself since the invention of the battery, the real reason for its occurrence is not yet well understood. If the operation be watched carefully for a little while, it will be noticed that the formation of gas becomes less rapid, and after a time it will cease altogether. If some means be provided for observing the strength of the electric current flowing through the circuit, it will be seen to diminish, and finally the current will almost entirely cease. An examination will show that the bubbles of gas have adhered to the copper plate in great numbers; and, if they be carefully removed by means of a feather or a splinter of wood, the current will suddenly increase, and the operation will continue as before until the same condition of things is again reached.

The stoppage or diminution of the current on the appearance of the gas upon the copper is attributed to what is called "polarization." It was first distinctly described by Ritter, who found that when two platinum wires were immersed in water, and a current was passed from one to the other, so that oxygen appeared at one of them and hydrogen at the other, if they were disconnected from the battery and joined through a conductor, a current in this new circuit would exist for a short time, the two wires acting like the plates of a battery. But in this case the direction of the current was opposite to that of the original circuit, showing that the electromotive force of what he called the "secondary" battery was opposite to that of the battery from which it was charged. He found that a Volta's pile might be constructed out of disks of the same metal; and, while it would not of itself exhibit any electrical properties, after it had formed a part of a circuit containing a battery of an ordinary form for a short time, it became an independent source from which a current could be drawn. This was the beginning of secondary or "storage" batteries, to which so much attention has been given during the past few years.

A similar condition of things exists in the simple cell described. The presence of the leaf electroscope; Leyden jars were charged by it; sparks were produced by it; in short, it seemed clear that the two extremities of the pile or battery were in opposite states of electrification, one being positive and the other negative, and that they acted as any other oppositely electrified bodies would act. The battery, however, differed remarkably in two respects from all previously known devices for producing electricity. In the first place, the difference in the electrification of the two poles was extremely feeble; that is to say, the difference in the electrical states of a glass rod and a bit of silk, after a few strokes of the one on the other, is several thousand times greater than that of the two poles of a single battery-cell. It was soon discovered that this "polar difference," or intensity of electrification in a battery, depended on the number of pairs or cells, and not at all on their size. As most of the effects of the pile first studied depended almost entirely on this "intensity of electrification," it was naturally found that small plates were just as satisfactory as large ones, "provided, only, that their number was sufficient;" and it was also observed that the results depended on the metals used for these plates rather than on the nature of the liquid in which they were immersed.

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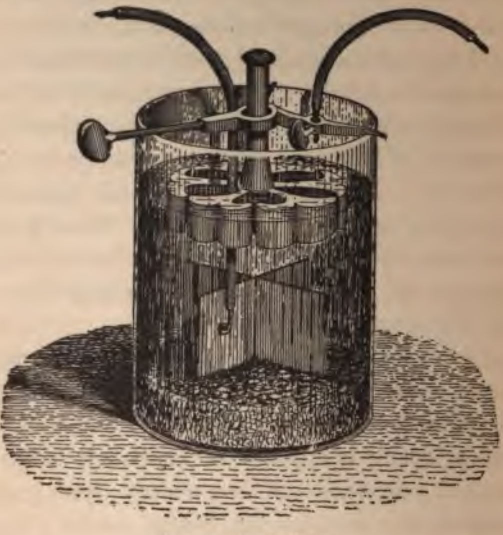
The primary cause of the flow of the current is the electromotive force. If the two poles of a battery, or any two electrified bodies which differ in potential, be joined by a conductor, flow of electricity will take place, precisely as flow of water will occur if two reservoirs differing in height or head be connected by a pipe. The older electricians found that in discharging a Leyden jar, if an imperfect conductor, such as a moistened thread, were used, the operation required greater time and the strength of the current was correspondingly less; exactly as, in the case of the reservoirs, if the connecting pipe be small, or if for any other reason it offer considerable resistance, the quantity of water passing in a unit of time will be small. In other words, with a given electromotive force, the strength of the current will depend upon the resistance of the circuit, being inversely proportional to the same.

the Daniell, the porous cup being dispensed with, and the separation of the two liquids being accomplished through the difference in their density.

Upon the invention of a satisfactory battery for the production of electricity, in connection with the capabilities of the electric current which have now been considered, two transformations of electric energy become available: it can be converted into heat and light, and into chemical energy. The beginnings of its useful-



The gravity battery.

ness in the first direction have already been referred to. Davy produced a powerful electric light; but his battery was inefficient, and his "lamp" was exceedingly imperfect. Immediately after the invention of Grove's and Bunsen's batteries, by means of which a powerful electric current could be maintained for hours at a time, the attention of scientific men and inventors was turned to the problem of electric lighting. Foucault devised an automatic regulating lamp, and instead of common charcoal a vastly better carbon was obtained from the hard coke of gas-retorts. It was found that from forty to one hundred cells of Grove's or Bunsen's battery would maintain the electric arc. It was used in photography, for public illuminations, in theatres, and for scientific illustrations, whenever a powerful source of light was desired.

It should be noted, however, that all of the numerous regulating lamps which came into use depended for their operation upon a principle at present assumed to be undiscovered. It is possible, but hardly probable, that, had it remained unknown to the present time, some mechanical substitute for it might have been devised. But the serious obstacle in the way of the introduction and use of the electric light was its cost, and the annoyance and trouble arising out of the management of large batteries. Indeed, it is difficult to imagine, that, without aid from another source, electric lighting could have been to-day as far advanced as it really was forty years ago.

In the application of the electric current to chemical operations there was more lasting success. In addition to the brilliant showing it has made in the advancement of science, through the labors of Davy and others, it has contributed largely to the welfare of man in the development of the art of electro-metallurgy. The chemical action of the current, and its power to separate metals from their compounds and deposit them in a pure state, have already received consideration.

In 1838, Jacobi, of the St. Petersburg Academy of Sciences, announced that he had succeeded in thus obtaining copper plates which were exact representations of original designs and engravings, from which they were copied. It also appears that an Englishman named Spencer had at about the same time done the same thing, and that still another was just on the point of doing it. It had before been noticed, that, when the copper which is deposited on the copper plate of the Daniell cell was removed, it reproduced all the irregularities of form of the plate, even to the minutest scratch.

This observation was doubtless the beginning of the process of electrotyping. The growth of the art during the half-century of its existence has been enormous. Electrotyping with copper was quickly followed by the application of the process to the deposition of silver, gold, and later of nickel, iron, and, indeed, of most metals, although in some instances serious difficulties had to be overcome before the operation was successful. It is applied to the production of copies of medals, engravings, etc.; and, in fact, if the useful applications of electricity were confined to electro-metallurgy alone, the science would have much to boast of.

Could the electric telegraph have existed if heat and chemical action were the only known effects of the electric current? The answer must be in the affirmative. Its development under this assumption would not only have been possible, but tolerably certain.

Franklin and others succeeded in transmitting the electricity produced by friction through wires of considerable length, and the idea of using it as a means of exchanging signals between distant points occurred to many of the older electricians. Shortly after the discovery of the decomposition of water by the electric current by Nicholson and Carlisle, a system of telegraphy, based on the chemical action of the current, was proposed by Sommering. Decomposition has found many applications in modern telegraphy, and it is not safe to say that it will not play a much more important part in the telegraphy of the future. The utilization of the heating effect of the current for the same purpose is possible, but not extremely probable, although a system depending upon it has been patented.

It is interesting to note that an electric telegraph would have been possible, and was, indeed, proposed, based upon another effect of electricity quite distinct from either of those referred to above; that is, the power that it possesses of producing muscular contraction. The legs of a frog might be used as a receiving instrument; and, in fact, the legendary lore of the telegrapher contains many accounts of messages having been read in an emergency by placing two ends of the circuit upon the tongue. But the problem was destined to receive its solution at last through the linking-together of two natural phenomena, both of which had been known from the earliest times.

CHAPTER III.

OERSTED'S DISCOVERY AND THE ELECTRO-MAGNET.

ALL the world would doubtless be glad to unite in doing honor to the author of one of the finest discoveries of all time, could his identity be revealed. There is little chance, however, that the discoverer of the magnet, or the discoverer and inventor of the magnetic needle, will ever be known by name, or that even the locality and date of the discovery will ever be determined. The first observer of the attractive power of certain ores of iron may or may not have found their tendency to assume a certain direction when freely suspended. The transfer of this power and tendency to pieces of iron and steel, and thus the invention of the mariner's compass, constitutes an advance upon the observed attraction of the ore so considerable as to challenge the admiration of those most skilled in modern methods of research.

It has been claimed by Humboldt and others that the earliest known use of the magnetic needle was among the Chinese, in whose history it is referred to at a date as early as twenty-six hundred years before the Christian era. It is not there described as a *mariner's* compass, but seems to have been used to guide armies over the great plains of the interior. It is represented as having been carried in a wagon, and consisting of the figure of a man whose extended arm constantly pointed towards the south. It is interesting to note that among the Chinese the needle was described as pointing to the south, precisely as among Western nations it is spoken of as indicating the north. The custom of China in this respect prevailed also in Japan. Although the Greeks and Romans were aware of the attractive power of the magnet, they were evidently ignorant of its polarity, or directive power. Unfortunately, nearly all references to it in the literature of that period are so undoubtedly fabulous that they are of little real value.

The name "magnet" is unquestionably derived from Magnesia, a city in Asia Minor, where the first specimens were probably found; although Pliny derives it from Magnes, a herdsman who found himself rooted to a magnetic rock by the nails in his shoes and the iron points of his staff. Magnets were made use of in the ceremonies of the temple, and by their aid statues of the gods were suspended in mid-air. A statue of Venus, made from a magnet, held an iron statue of Mars, suspended; and every one knows the story of Mahomet's coffin, which "soared in a sanctuary built of magnetic stones." The tradition of a magnetic mountain at sea, over which a ship with iron bolts and nails could not sail in safety, is found in many languages. In Japan it is a popular belief that a magnet loses its power a short time previous to an earthquake, and it has been used as a prophetic seismoscope. The magnet has also been credited with extraordinary medicinal, and, indeed, moral powers. In addition to its power to cure various diseases, it was thought to possess the very desirable quality of enabling its owner to win friendship and love, to succeed in business, and to discover the secret feelings of others. It was solemnly affirmed to be capable of revealing whether a bride had accepted a husband from motives of affection, or from considerations of a pecuniary nature.

Even brief reference to such absurdities would be inexcusable, were it not for the purpose of inviting attention to the fact, that, as with electricity, the present age is not free from impositions of a similar character. Only a few years ago, in a city which is the seat of a university and sundry other educational establishments, the writer happened upon a dealer who was doing a thriving business in the sale of small fragments of loadstone, to be used for psychical rather than physical research.

The use of the compass does not appear to have been known among Western nations before the twelfth century. The tremendous extension of human knowledge through the extension of human intercourse, which rapidly followed during the succeeding centuries, must be largely attributed to its use; and a feeling of astonishment results from a contemplation of the fact that the Chinese, according to their own records, were in possession of the secret of ocean navigation for four thousand years previous to the time of Columbus, and yet almost no use was made of it.

As stated in a previous chapter, the magnet and magnetism received their first scientific treatment at the hands of Dr. Gilbert. During the two centuries succeeding the publication of his work, the science of magnetism was much cultivated. The distribution of the magnetism of the earth was investigated, and methods of making artificial magnets by the "touch" of the natural were experimented upon, and considerable improvements devised. The development of the science went along parallel with that of the science of electricity, as outlined in the first chapter, although the latter was more fruitful in novel discoveries and unexpected applications than the former. It is not to be imagined that the many close resemblances of the two classes of phenomena were allowed to pass unnoticed. Both had been known from the earliest times; both exhibited attraction, both repulsion, and under decidedly similar conditions. In both casés the law of attraction and repulsion was that of inverse squares. But nearly all bodies were known to be capable of electrification, while hardly more than one or two could be magnetized. Electrification could be produced under almost all circumstances, and electricity made to appear where none apparently existed before. Magnetism had to be borrowed; and although the touching or inducing magnet lost none of its power in establishing polarity in a piece of steel; and while it was possible, by proper manipulation and combination, to produce a magnet of greater strength than that used as the source,—there was no known process by means of which the condition of magnetization could be created from the beginning.

Notwithstanding these differences, there was enough resemblance to suggest an intimate relation; and the connecting link was sought for by many eminent philosophers during the last years of the eighteenth and the earlier years of the present century. The discoveries of Galvani and Volta revolutionized the science of electricity. The pile or battery of the latter was a powerful instrument for research, which, in the hands of hundreds of experimentalists, was rapidly working out the brilliant beginnings of an age of discovery destined to rival all others in the development of the physical sciences. Through the labors of Rumford, Davy, and others, the idea of the unity of the forces of nature begun to prevail. A belief in the close relationship of electricity and magnetism existed generally among scientific men, and the age was ripe for the splendid discovery, made in the winter of 1819–20, through which that relationship was revealed.

Its author was Jean-Christian Oersted, a Dane. The son of an apothecary who practised his profession in a village of less than a thousand inhabitants, his early education was intrusted to a wig-maker and his wife, who taught him to read his mother-tongue and also German. So quick in learning and so attentive was the child, that the amateur schoolmaster ventured to offer him a little instruction in arithmetic, his own knowledge of the subject being confined to addition and subtraction. He was soon beyond the possibility of receiving aid from his master, but the kindness of others in lending him books rendered such assistance unnecessary. At the age of twelve years he entered the pharmacy of his father as an apprentice. It appears that this was a momentary disappointment to him, as he had resolved, even at that early age, to devote himself to the study of theology. The operations of the laboratory, however, soon excited in him an interest in chemical experiments, which led to an enthusiastic perusal and study of all chemical works within his reach, and undoubtedly contributed greatly to lay the foundation of his future career. He exhibited a taste for all learning, however, studying Latin and Greek, and at this early period showed a fondness for poetry and rhetorical studies, which he retained until the end of his life. Indeed, the degree of doctor of philosophy, which he obtained in Copenhagen at the age of twenty-two years, was granted upon the presentation of a thesis in metaphysics. A year later he was enabled to travel on the continent of Europe, visiting the principal cities of scientific activity, and charming all who came in contact with him by his modesty, as well as by the evident brilliancy of his genius. His career was definitely fixed in the direction of experimental science, and during his years abroad he saw much of the rapid development of the science of electricity, which had just received so powerful an impetus through the discoveries of Galvani and Volta. On his return he was appointed professor of physics in the University of Copenhagen. He was a skilful and enthusiastic lecturer, attracting large audiences on account of the eloquent and spirited manner in which he presented difficult subjects, his treatment of them being also clear and logical. During the succeeding period of fifteen years, he produced numerous original papers of great value, and he was greatly occupied in the consideration of electrical phenomena.

Through his philosophical studies Oersted had become fixed in the belief in the unity of the forces of nature, and he had, in common with others, expressed the opinion that magnetism would one day be found to be related to electricity. He had often tried to discover the connecting link, but hitherto all attempts had ended in failure. It was in the winter of 1819–20 that his efforts were crowned with success, and his victory was won in the presence of many besides himself. It was during the inspiration of a lecture before his pupils that the thought occurred to him to try a new mode of attack. A battery of considerable power was on the table, and near by was a suspended magnetic needle. He announced to his hearers what he was about to try, and then seized the wire joining the two poles, and placed it parallel and over the needle, but without touching the latter. Instantly the needle swung out of its position, and one of the most magnificent discoveries of modern science stood revealed as an accomplished fact. Oersted thoroughly worked up the experimental part of his discovery, and published it to the world about the middle of the year 1820.

If there was something dramatic in the way in which this discovery was made, there was something not less so in the manner in which it was seized upon by one of Oersted's contemporaries, developed, extended, and made to serve as the foundation for a tolerably complete superstructure, — the science of electro-dynamics.

The creator of this science was André Marie Ampère, born at Lyons, France, in 1775. Living at a time when France was rich in men of genius who were devoted to the physical sciences, no other contributed so much that is lasting in the literature of electricity as he, and the annals of the science nowhere exhibit a more brilliant performance than his analysis and extension of Oersted's experiment. On the 11th of September, 1820, he first learned of the

Copenhagen experiment, in which a magnetic needle was deflected by the electric current. On the 18th of the same month, in a paper presented to the academy, he announced the fundamental principles of the science of "electrodynamics." In the almost incredibly short time of one week he had worked over Oersted's discovery both theoretically and experimentally; he had made the capital discovery that magnetic effects could be produced from the current without the use of a magnet; he had shown that parallel wires, through which currents were flowing in the same direction, ought to attract each other, and he had proved by experiment that they did. To do this, he devised novel forms of apparatus, which are to be found to-day in every physical cabinet; and, finally, he had devised an ingenious hypothesis which brought the whole subject within the domain of mathematical treatment. It is safe to say that the science has at no other time advanced with such tremendous strides as during that memorable week.

On this joint work of Oersted and Ampère the whole structure of modern electricity may be said to rest, and with the establishment of this, its almost ample foundation, their names will ever be inseparably connected. Almost sufficient it was, but not quite, for the work of

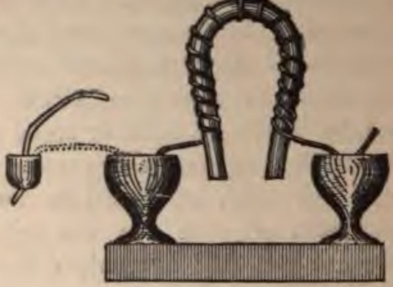
Ampère was destined to be supplemented ten years later by a discovery of such importance, and so fruitful in its results, as to give it equal rank with those of Galvani and Volta and of Oersted and Ampère.

Physicists were not idle, however, during these ten years, and many observations were recorded, which, on account of their great interest and their relation to the future advances of the science, are well worth considering. In the beginning, students of electricity were not agreed as to their interpretation of Oersted's experiment. Many believed that the conductor through which a current was passing assumed magnetic properties during its transmission of electricity, while Ampère's theory was based upon the assumption that magnetism was an electrical phenomenon. All were at first inclined to consider the action of the conducting wire upon the needle as in the nature of attraction and repulsion, the two phases of force with which they had become so familiar in the study of magnetism and the electricity produced by friction. A closer examination of the facts led to the correct view, that the direction of the motion of a magnetic pole, when free to move under the influence of a current flowing through a wire, was neither towards nor away from the wire, but in a line at right angles to a plane passing through the pole and the conductor.

This fact was thoroughly appreciated by Dr. Wollaston in England, who conceived the possibility of maintaining the continuous rotation of a wire about its axis in this way. He made several unsuccessful attempts to accomplish this, one of which was in the laboratory of the Royal Institution, in the presence of Sir Humphry Davy. The latter had as an assistant a young man named Michael Faraday. He was not present when the trial was made, but, entering the room afterward, heard some conversation on the subject between the two famous philosophers. In his spare moments he had given much thought to the subject of electricity, and had repeated for himself all experiments of moment which had been devised by others. In the latter part of the year 1821 he succeeded where Wollaston had failed; not, indeed, in producing rotation of a wire about its axis, but in causing a conducting wire to continuously rotate about a magnet, and a magnet to rotate about a wire, — two experiments now classical, and interesting as the first examples of continuous motion produced by electricity.

Among the many who took up the subject of electro-magnetism immediately after Oersted's discovery, was Ampère's distinguished countryman, Arago. In 1820 he and Davy independently discovered the interesting fact, that, if a copper wire through which a current is passing be plunged into a mass of iron filings, many of them will cling to it and to each other, clustering about it very much as if it were magnetic; but this will not occur if the filings be of brass, copper, zinc, etc. In the same year, Arago, led by the theory of Ampère, placed sewing-needles and pieces of steel wire within a glass tube, and, by winding a helix or spiral of wire through which a current was passing on the outside of the tube, succeeded in rendering them magnetic. In this way was established the important fact that not only could a current of electricity *influence* a magnet, but it was also capable of *producing* magnetism; the loadstone as a primary source of magnetism was dethroned, and the cell of Volta crowned in its stead.

A notable step in advance of this was made three or four years later by W. Sturgeon in England, resulting in the production of what is generally known as the "electro-magnet." He used soft iron instead of steel, finding that the former was capable of a much more intense magnetization with a given strength of current than the latter, although the effect only lasted while the current was flowing. He bent the iron into the shape of a horseshoe, and, by thus bringing its poles into the same plane, increased the convenience with which its power could be employed. He varnished the iron, in order to insulate the coils of naked wire which he wound in a spiral about it.



Sturgeon's magnet.

The lifting or sustaining power of these electro-magnets, the practically instantaneous production of this power at the instant the circuit was closed, and the rapidity with which it died away when the current from the battery ceased to flow, made them objects of immediate interest to both the learned and the unlearned. Many foresaw the important practical applications likely to be made of so convenient a mode of suddenly bringing a considerable force into existence, and as suddenly annihilating it. Those most familiar with the subject, however, recognized the imperfections of the operation, and realized that much further development was necessary to its utilization.

In this condition the subject was taken up by a distinguished American physicist, through whose genius and experimental skill the electro-magnet was rapidly perfected, and made to exhibit such enormous power as to appear at that time little less than marvellous. This important advance was made by Joseph Henry. Educated in the common schools of Albany, N. Y., and at the Albany Academy, he became, in 1826, professor of mathematics in the latter Institution. He at once entered upon a series of experimental researches in electricity, which resulted within a few years in discoveries which rendered their author celebrated, both at home and abroad.

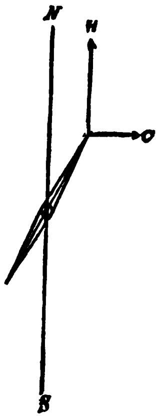
In the construction of the electro-magnet he introduced a principle suggested by the galvanic multiplier of Schweigger, to which reference will be made hereafter. Instead of varnishing or otherwise insulating the iron core, and winding a single spiral of wire about it, he insulated the wire by covering it with silk, and then made many turns of the wire about the core. On his first small magnet he put thirty-five feet of wire, making about four hundred turns. The superiority of this method was at once demonstrated. This magnet was exhibited in March, 1829. A further improvement consisted in winding the core with several coils, the ends being left free. When these ends were properly soldered to the zinc and copper of the cell, so that the current divided among the different coils, the strength of the magnet

Henry's magnet. From a cut published by Henry.

was found to be greatly increased. He experimented upon the proper length of the coil to be used with batteries of different forms, reaching the highly important conclusion, that either a very long wire, making a single continuous coil, may be used, or several shorter ones arranged as above, as circumstances may require; but that in the first case the battery must consist of a number of pairs of plates arranged in series, — that is, by joining the zinc of one cell to the copper of the next, and so on, as Volta had done originally, — while in the second case it must consist of a single pair of large surface.

By an extended series of experiments he brought his new method to a high degree of perfection. The current from a single pair of plates only one inch square excited one of his magnets so that it sustained eighty-five pounds; with another, excited by a single cell having less than half a square foot of surface, and requiring half a pint of dilute acid, a weight of six hundred and fifty pounds was sustained; and, when a slightly larger cell was used, this was increased to seven hundred and fifty pounds. In 1831 he constructed a magnet, the iron core of which weighed less than sixty pounds, but which was capable of sustaining more than a ton, and afterwards another which carried not less than thirty-six hundred pounds. Although these feats in electro-magnetism have been excelled within the past few years, they are important as indications of the rapid expansion of the subject in the hands of Professor Henry more than fifty years ago. In demonstrating the possibility of constructing an electro-magnet of almost any desired power, he was laying the foundation for the most important processes of utilizing the energy of the current which have since come into use.

The galvanic multiplier of Schweigger, the construction of which suggested to Professor Henry the possibility of improving the electro-magnet, was itself the first of a large family of electrical instruments, the existence of which must be regarded as absolutely essential to the growth of the science to its present dimensions. It was really little more than an extension and application of Oersted's discovery. When a wire is stretched over a magnetic needle, as described in the consideration of that famous experiment, if it be bent and brought back *under* the needle and at the same distance from it, the effect on the needle, of the current which passes through it, will be found to be doubled. If another loop around the needle be taken, its effect will be again multiplied, so that by making many turns of the wire the effect is so magnified that the instrument becomes sensitive to currents which are exceedingly feeble. It therefore becomes a galvanoscope, and is invaluable, in all electric experiments, for the detection of minute currents. It would seem that its sensibility might be increased indefinitely, but two obstacles are encountered which are insurmountable in practice. It is, of course, impossible to wind all elements of the coil at the same distance from the needle; so that every layer which is put on is less effective than that upon which it is wound, by reason of its increased distance. Again, any increase of the length of the wire increases the resistance offered to the passage of the current; so that for a given number of battery-cells, or a given electromotive force, the current will be diminished according to a simple law already referred to. Nevertheless, by making the needle very small, very light, and giving it a very free suspension, any desired degree of sensibility may be reached. But the galvanoscope is readily converted into an instrument of greater dignity and value, known as the galvanometer. When the needle is at rest in the magnetic meridian,



Showing the action of two forces on a magnetic needle.

H represents the action of the earth's magnetism, and *C* that of the deflecting current.

the resultant of the forces acting on it is zero. The action of a current sent through the coils, assumed to be parallel with the same meridian, is to deflect the needle from this position with a force which becomes less effective as the deflection increases. But the effectiveness of the earth's magnetism increases with the deflection; so that, when the needle is being moved from its normal position, the deflecting force constantly diminishes, while that tending to restore it constantly increases. In some positions of the needle these two forces will balance each other, and in that position it will finally rest. The deflecting force depends upon the strength of the current; so that, by the use of the galvanometer, current-strength can be accurately measured, and its value expressed numerically, thus subjecting it to rigorous mathematical treatment.

The accuracy with which all electrical quantities may be measured, by processes mostly depending on the use of this instrument, must command the highest admiration of all who realize the slowness with which science in general has been subjected to treatment by methods of precision; and unquestionably the rapid progress of the science of electricity is to be largely attributed to the early use of quantitative processes.

It will be seen from the foregoing that in the decade following Oersted's discovery the science of electro-magnetism grew with wonderful rapidity. In the beginning the Danish philosopher had shown the existence of a relation between electricity and magnetism of which the world had before been ignorant. Within ten years a ton of weight was sustained by means of a battery less powerful than that which had first enabled him to deflect his delicately suspended needle. The possibility of producing motion and doing work at a distance, by means of the newly discovered principle, was clearly recognized and distinctly announced by many physicists, and particularly by Joseph Henry. The application of electro-magnetism to the problem of telegraphy was suggested by many, and the ingenious in several countries set themselves at work to accomplish the desired end. In spite of the appearance of many unexpected difficulties, before another decade passed the thing was really done, and through science the world was put in possession of an invention destined to create a new industry, which, by its influence upon the human race, distinguishes the nineteenth century above those that preceded it more than all else.

CHAPTER IV.

WHO INVENTED THE ELECTRO–MAGNETIC TELEGRAPH?

THE reader of the foregoing pages will have decided already that the answer to this question cannot be given by naming one man. He will know that the idea of telegraphing by means of electricity was nearly a hundred years old before it became an accomplished fact. The ingenious arrangements of the older electricians for telegraphing by means of electricity produced by friction were little more than philosophical toys, although the authors and promoters of these methods fully appreciated the importance of the idea, and in some instances made praiseworthy efforts to realize it in practice. As early as 1774, Lesage constructed an electric telegraph consisting of twenty-four wires, at the end of each of which was a pith-ball electroscope; and in 1816 Ronalds constructed a line of one wire, using pith-balls and two synchronous wheels. He endeavored to bring the matter to the attention of the British government, and received the really exquisite reply that "telegraphs of any kind are now wholly unnecessary, and no other than the one now in use will be adopted." A very important step was taken in 1828 by Harrison Gray Dyar of New York, who invented a method of recording in which a discharge was made to pass through a sheet of moistened litmus paper moving at a uniform rate. A line was actually set up and experimented upon in the same year. In all of these systems it was proposed to use frictional electricity ; but, even with the present vastly increased power of production and control of this species of electricity, a successfully operating telegraph would hardly be possible.

The real electric telegraph began with Galvani and Volta, and, as already intimated, more than one system has been fairly successful, the fundamental principles of which were understood before the close of the first decade of the present century. The complete solution of the problem, however, would unquestionably have been postponed for many years but for the discovery of Oersted in 1820. Immediately on its announcement, the telegraph became the dream of many men in many countries. Concerning its origin and growth, the great majority of Americans have been singularly mistaken. The popular impression seems to be that it is exclusively an American invention, and that in America it was almost exclusively the product of the genius of one man. It hardly need be said that these impressions are extremely erroneous.

Ampère, whose genius had accomplished so much in the early development of the theory of electro-magnetism, was probably the first to suggest its use in telegraphy. His method was founded on Oersted's experiment. If a needle could be deflected by an electric current, if this could be accomplished by a wire or wires of great length, and if these movements of the needle could be converted into a code by means of which letters or words could be expressed, then the electro-magnetic telegraph was possible. Ampère's suggestion was to employ a number of wires, and to deflect a number of needles. Considerable attention was given to the development of this idea for a number of years following the discovery of its fundamental principle. The progress of the invention was seriously retarded by the publication of an investigation by Barlow, of the Woolwich Military Academy, in 1825, in the course of which he discovered that there was an enormous diminution in the power of a current to produce effects with an increase of distance, and which led him to declare that the project of an electro-magnetic telegraph could not possibly be successful.

The invention of the electro-magnet by Sturgeon apparently offered a new solution of the problem; but, owing to the imperfect construction of his magnets, the difficulty of overcoming distance was not diminished. This obstacle, which seemed for a time to be insurmountable, was conquered by Joseph Henry in the manner already described. Out of Oersted's experiment grew the needle-telegraph, — a form which prevailed for several years in Europe, until it gave way before the evident superiority of that founded on the electro-magnet, which grew out of the researches of Henry, and which is generally known as the Morse or American system.

The needle-telegraph was first in the field, and its working will first be considered. Many of its earlier forms appear as suggestions only, no attempt having been made to put them in practical operation. In 1832, however, Baron Schilling, a Russian counsellor of state, had a working system in which thirty-six needles were used, and which included an ingenious alarm for calling the attention of the receiving operator. It consisted of a device by means of which the movement of one of the needles released a small ball of lead, which, by dropping he determined the velocity of the electric discharge. Although the result of these experiments was really of no great value, the method employed is now classic, and it has furnished the means of solving some of the most important fundamental problems in physics. His conclusion was, that an electric discharge traversed a copper wire one quarter of a mile in length at a speed of 288,000 miles per second; and this was long accepted as the true "velocity of electricity;" as it doubtless correctly represented the velocity of discharge under the particular conditions of Wheatstone's experiment. More recent investigation of the subject has shown, however, that it is no more correct to assign a definite velocity to electricity than to a river. As the rate of flow of the latter is determined by the character of its bed, its gradient, and other circumstances, so the velocity of an electric current is found to depend on the conditions under which flow takes place. It is greater in short than in long lines, and depends on the character of the line, being much greater in a line suspended in the air than on one insulated with gutta-percha and buried as an ocean-cable. It depends, also, upon the *sensitiveness of the receiving instrument*, from which it will be understood that what is here stated concerning velocities refers to the time required for the production of certain effects through certain conductors, and that nothing is affirmed or assumed as to the nature of the current or its motion, of which Clerk Maxwell says: —

> As to the velocity of the current, we have shown that we know nothing about it: it may be the tenth of an inch in an hour, or a hundred thousand miles per second. So far are we from knowing its absolute value in any case, that we do not even know whether what we call the positive direction is the actual direction of the motion or the reverse.

In the measurement of this apparent velocity of the current, various results have been obtained in practice, much lower than that of Wheatstone, being in some cases 1,400 miles per second, and in others 3,000, 18,000, 60,000, and so on. As before stated, the great merit of Wheatstone's work on the problem was the device of the revolving mirror, which has enabled physicists to measure intervals of time incredibly small.

Wheatstone's interest in and connection with telegraph enterprises began in 1835, in which year he exhibited one of Schilling's telegraphs in his lectures, and in the year 1837, when he formed a copartnership with W. F. Cooke, for the purpose of introducing the electric telegraph into England. Their first patent was taken out in 1837; and the system required five needles, with as many wires for their manipulation, and a sixth wire for the "return current." Wheatstone developed numerous improvements during the next few years, and as early as 1840 a dial instrument showing the letters of the alphabet was patented. Numerous difficulties were encountered and overcome, and by 1844 the enterprise was on a sound financial basis.

The operation of working a telegraph was at first naturally regarded by most people as a mystery, and by many as a fraud. When communication was established between Paddington and Slough, a distance of about twenty miles, the wires were insulated partly by silk, and were suspended through goose-quills attached to posts along the Great Western Railway. The telegraph company not only invited the patronage of the public in a legitimate business way, but it also exhibited its apparatus as a novelty, as is shown by the following curious and interesting announcement, which appeared in 1844: —

"UNDER THE SPECIAL PATRONAGE

OF ROYALTY.

INSTANTANEOUS COMMUNICATION

between Paddington and Slough, a distance of nearly twenty miles, by means of the

ELECTRIC TELEGRAPH,

which may be seen in operation daily, from nine in the morning till eight in the evening, at the

GREAT WESTERN RAILWAY,

Paddington Station, and the

TELEGRAPH COTTAGE

Close to the Slough Station.

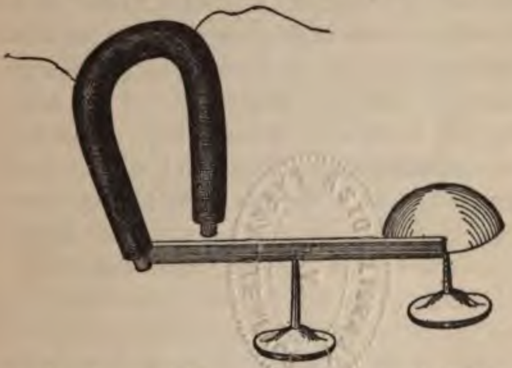
Admission One Shilling ; Children and Schools, half price."

This short line had already established itself in the good graces of the people, through its instrumentality in securing the arrest of a criminal.

The construction expenses incident to the use of a large number of wires, to say nothing of other difficulties, led to the reduction of the number of needles employed to two, and one in which a single wire was sufficient. A single needle is now almost universally employed wherever the needle system has survived competition with other forms. The movements of the needle are readily applied to signalling the alphabet by combinations of swings to the right and to the left. It will be remembered that in Oersted's experiment a reversal of the current through the wire reversed the direction of the deflection of the needle. The operating key is so arranged, that, when its handle is turned to the right, a current is sent through the line which deflects the needle in the same direction; and, when the opposite movement is made, the current is reversed, and the needle swings to the left. The alphabet may and generally does correspond with what is known as the "Morse Code." A swing to the right is interpreted as a long signal or dash, and one to the left as the short or "dot" signal of the Morse system.

For many years the needle system of telegraph was used almost exclusively in Great Britain, although it never succeeded in gaining a foothold on the continent of Europe or in any other part of the world. Its principal advantage is the comparatively feeble current required to work it; but it is slower than the Morse system, and does not lend itself to sound-reading, or to methods of securing written records of the messages which it transmits. It has therefore almost entirely given way to other systems, even in Great Britain, although, as will be seen, it is retained in connection with long ocean-cables, and within a few years a self-recording device has been successfully applied to it.

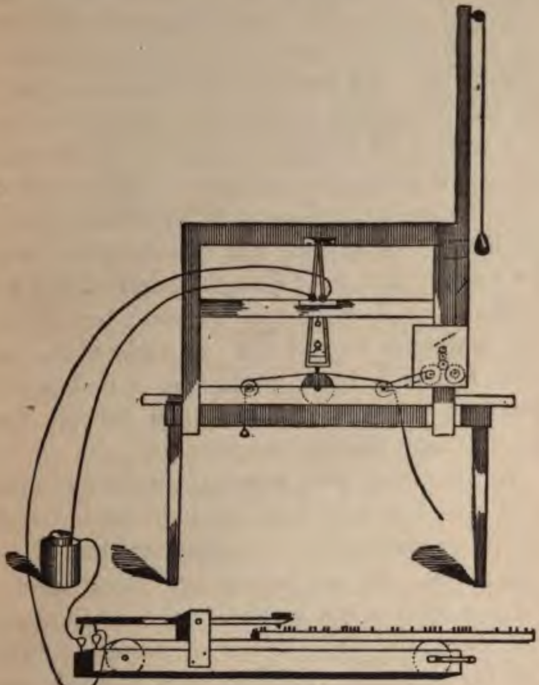
The system of telegraphy now almost universally in use is one which originated in America, and whose development was nearly contemporaneous with that of the needle system. In England the fundamental experiment about which the telegraph grew was that of Oersted; while in America the electro-magnet, as constructed by Sturgeon and improved by Henry, was made the basis of the invention. As there has been much misunderstanding concerning the distribution of credit for the evolution of this system of telegraphy, it may not be out of the way to consider at some length its more important phases.



Henry's arrangement for receiving signals, as exhibited in Albany in 1832. — From a cut published by Henry.

Much credit must always be accorded Professor S. F. B. Morse, through whose indefatigable labors and persistent faith the commercial value of the enterprise was first established.

Born in the last century, he reached the age of forty years before having apparently given a single thought to what was to be the great work of his life. His early training was that of an artist, although he was always fond of scientific pursuits. He studied in London under the best masters, and was highly successful in his chosen profession, some of his works bringing him great renown. His first conception of an electro-magnetic telegraph seems to have arisen out of a conversation with a friend on board the packet ship Sully, on a voyage from Havre to New York in 1832. In this conversation some experiments of the French were described, in which electricity had been transmitted through long distances. Some one remarked, "It would be well if we could send news in this rapid manner;" to which Morse at once replied, "Why can't we?" And from that moment he devoted his energies to accomplishing the desired end. During the remainder of the voyage, he made drawings of forms of apparatus, and considered the translation of signals into an alphabet. He does not appear to have been familiar with the principles of electro-magnetism at that time, and it is affirmed that the use of an electro-magnet was suggested to him by the gentleman with whom this first discussion was held. On reaching New York, he began experimenting upon the subject, and in 1835 he had completed a working model of his recording instrument. It was not until 1837, however, that he was able to put two of them in operation at the extremities of a short line,

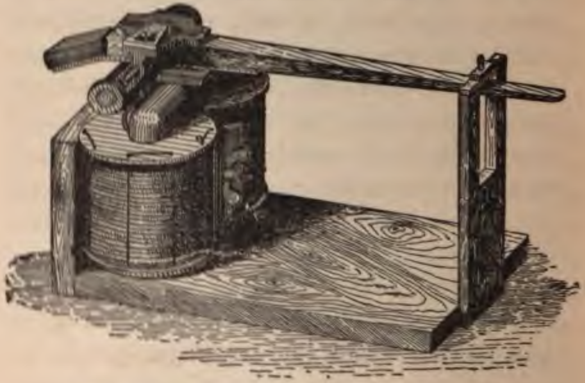


The earliest model of the Morse system — with type transmitter.

so as to be able to both receive and send signals. In that year his apparatus was exhibited to many people in the University of New York. In the following year he made an unsuccessful effort to secure aid from Congress to establish an experimental line between Washington and Baltimore. He then visited Europe, but failed to secure patents for his inventions. During the session of Congress of 1842–43, he again struggled to secure recognition and an appropriation to enable him to build his experimental line. The scheme was considered Quixotic by many members of Congress, and at the last moment he despaired of success; but during the midnight hour of the last night of the session, March 3, 1843, a bill was passed, appropriating thirty thousand dollars for the line from Washington to Baltimore.

In the mean time many apparently insuperable obstacles had been encountered in the attempt to secure the successful working of the apparatus. In the beginning, Morse used a magnet with a few turns of wire, as Sturgeon had done, and a single cell of battery. With this his instrument failed to work through more than a few feet of wire. This difficulty was surmounted by taking advantage of the researches of Henry, using what he called an "intensity" magnet, and many cells of battery in stead of one. Although by this method signals could be transmitted through a comparatively long distance, they were still too feeble to print themselves upon the moving strip of paper. To overcome this difficulty, it was only necessary to introduce the device known as the "relay," by means of which the work on the main circuit was reduced to making and breaking the current of a local battery, on the circuit of which was the recording machine. In this short circuit the current was easily made strong enough to operate the registering instrument. This method of working had been devised nearly ten years before by Henry, and it had also been used by Wheatstone in his needle system.

In Morse's first attempt to build his experimental line from Washington to Baltimore in 1844, the wires were placed under ground instead of upon poles; but the former method was soon abandoned for the latter, which had already been in use for several years in Europe and elsewhere. In Morse's first instrument the "transmitter" was mechanical; that is to say, the message to be sent was first "set up" in "dots and dashes" by arranging long and short type in proper order in a line, and by the regular movement of this line of type the circuit was closed for periods of time necessary to the reproduction of the dots and dashes at the other end. Morse did not imagine that signals could be made by the hand with sufficient regularity to produce legible records. This was soon discovered to be possible, however, and, for the clumsy, mechanical transmitter, the simple key in use to-day was substituted, by the skilful manipulation of which the operator produces dots and dashes with such regularity and rapidity as to leave nothing to be desired.


Morse's Patent Office model of magnet and armature.

The statements made above, derived from papers of an official character, may be summarized as follows: In the Morse telegraph are found, the battery; for which credit must be given primarily to Volta, and then to Daniell, who in

1836 devised a battery nearly constant in its strength, — an essential requisite to its application to the telegraph; the key, or transmitter, which, except in details of construction, is practically that in use since experiments on electricity were begun; the receiving instrument, of which the essential feature is the electro-magnet, due primarily to Sturgeon, but modified and improved so as to be available for this work by Henry; the relay, by means of which the local current is put in operation, which was used by Henry and also by Wheatstone; the line wire suspended on poles, — a method first practically used by Dr. W. O'Shaughnessy at Calcutta in 1839.

While it appears, therefore, that Morse cannot justly claim priority in the discovery of a single scientific principle involved in the telegraph, it must be admitted on all hands that he played a most important part in its development. In Europe all effort had been in the direction of the use of the needle system. Morse was quick to see the advantages of the electro-magnet, and especially the ease with which it could be made to leave a permanent record of the message. His use of a simple armature with to-and-fro motion, armed with a style, or pencil, which marked long or short lines upon a moving slip of paper, and his alphabet made up of these dots and dashes, show great ingenuity and mechanical judgment. As a measure of the value of his system, compared with the English, it is sufficient to repeat that to-day it has driven nearly every other from the field.

While the essential features of the Morse system still remain, modern instruments and methods of working show many important modifications. In this country the register by means of which the signals were printed as they were received has become almost entirely extinct, through the interesting discovery, by the early operators, that reading from the sound of the armature as it played to and fro was not only possible, but more expeditious and vastly more convenient than from the printed slip. Although the introduction of the Morse system in Europe, and especially in England, was largely due to the advantage which it offered in furnishing a permanent record of the message, the greater convenience of reading by sound is fully appreciated there, and that method of receiving is becoming every day more common.

In the two principal systems of telegraphy which have now been described, it will be observed that differences exist in receiving instruments rather than in other parts. It will be impossible to discuss, or even to mention, all of the innumerable devices which have been suggested, or which have been practically developed, through various combinations of the elements involved in these systems. But there has been another claimant for public favor, of which brief mention has already been made, whose fundamental principle is older than the needle or the electro-magnet. It is that in which the registration of the message is accomplished by means of chemical decomposition. Experiments upon this method were made at an early day, in which as many wires were used as there are letters of the alphabet: each wire led to a small cup or tube containing water, into which was plunged the extremity of the "return wire," one of which would serve for all of the "leading" wires. Each tube was marked with a letter, and, when it was desired to signal any particular letter, it could be done by closing the circuit through the proper tube, thus causing bubbles of gas to appear. This was essentially the system of Sommering of Munich, who constructed a model in 1809. A curious and ingenious feature of his method was a device for the setting of an alarm so that the operator might be relieved from the necessity of constantly watching the glass tubes. It consisted of a sort of lever, on the long arm of which was a small inverted bowl, covering the open end of one of the tubes in which gas was evolved. On the short end was a small metal ball, free to roll off when the lever was slightly tipped. If the operator at the distant end wished to open communication, he closed this particular circuit for a minute or two, during which time gas was generated. This collected in the inverted bowl, and, in virtue of the upward pressure of the gas, the lever was tipped, the ball would drop, and the alarm was set off.

The first realization of a practical system of telegraphy based on electro-decomposition was by Alexander Bain of Edinburgh. He took advantage of the fact that many salts are decomposed with the utmost facility by electricity, and by extremely feeble currents, and that this decomposition can be rendered evident through a recomposition, in which colored compounds are produced. If a little iodide of potassium be dissolved in water, and a little starch paste be added, the mixture will show a blue color about the positive pole when a very feeble current is passed through it. If any kind of porous paper be soaked in this liquid, and placed on a metallic plate connected with the negative pole of a battery, a blue mark will be made upon it wherever touched by the positive pole. From this the essence of Bain's invention will be readily understood. Imagine the paper to have a uniform movement over the metal plate, and a metal style connected with the line-wire to rest upon its upper surface. As long as no current is passing, no mark will be made; but, when the key is closed at the other end of the line, the style leaves a blue trail as the paper passes under it. It is only necessary to adopt an alphabet of long and short marks, or "dots and dashes," to complete the device. Bain's system was patented in England in 1846, and was introduced into this country in 1849. A number of lines working the system were erected, some of them of great length, and the Bain telegraph was at once successful and popular. After a few years, however, it was displaced by the Morse system. It is in most respects the simplest of all telegraph systems; and, in spite of its early rejection, it possesses decided merits, among which are the ease with which it can be adapted to rapid automatic telegraphy, and its ready application to autographic transmission. Further developments will be required to enable it to compete successfully with its long victorious rival.

The better-known effects of electricity are as follows: Electro-static attraction and repulsion, heating effects, chemical decomposition, electro-magnetic effects, physiological effects. Ronalds and the older electricians relied upon the first of these as a means of producing signals at a distant point. Among the numerous efforts to avoid interference with the Morse patent was a telegraph system in which the second was utilized. The current was made to pass through a short piece of thin platinum wire, which, becoming red-hot, burned holes, long or short, in a moving strip of paper. Sommering, Bain, and others, have utilized the third; Schilling, Gauss, Steinheil, Wheatstone, Morse, and many others have depended upon the fourth; while experiment, and occasionally necessity, has demonstrated the possibility of making use of the fifth. It has also been proposed to use other, more obscure effects of electricity for telegraphic purposes; but the telegraph of to-day is the electro-magnetic telegraph. Practically, all other systems have been abandoned for this. No attempt can be made here to describe the numerous, and in many instances wonderful, modifications and improvements which have been ingrafted upon the original stem, involving devices for rapid and automatic transmission, machines for printing the message in Roman characters as fast as received, instruments for repeating the message from one line to another, etc. Two or three extensions of original methods, which involve new principles or especially novel features, will be briefly considered in the following chapter.

CHAPTER V.

MULTIPLEX TELEGRAPHY AND SUBMARINE CABLES.

THE rapid growth of the electric telegraph during the decade from 1840 to 1850, and its marvellous performance, justly excited the curiosity and challenged the admiration of all intelligent people. Within a few years after its first introduction, it grew to be an important factor in business and social life, and many understood something of the philosophy of its operation. Few, however, were at first willing to give credit to certain suggestions as to further possibilities of its improvement, and this was particularly true when it was asserted to be possible to transmit simultaneously two messages in opposite directions over the same wire. Although this has now become an all but universal practice on lines doing a large amount of business, it is not too much to say that, to the great majority of the uninitiated, the operation is still a mystery; and this in spite of the fact that the principles involved are extremely simple.

As early as 1852 an American, Moses G. Farmer, devised a system of multiplex telegraphy, which was tested upon some of the shorter lines in Boston. Although the trials were fairly satisfactory, there existed a difficulty, inherent in the method, which Mr. Farmer was not at that time able to surmount. Within a very recent period the method has been revived, and the difficulty apparently overcome. If continued experience shall justify the confidence now felt in the new device, it must be admitted to be one of the most remarkable inventions of the time; but, as the principle involved is not that upon which duplex telegraphy has grown into success during the past ten years, its consideration must be deferred for the present.

The germ of the method now in use must be attributed to Dr. Wilhelm Gintl of Vienna, who in 1853 suggested the device which constitutes the basis of most modern systems. His attempts to put his system into practical use attracted the attention of inventors in Europe and America, and many efforts were made to reduce his idea to practice. Several improvements in his scheme were patented in Europe and in this country, but it was not until 1872 that a really trustworthy system was devised. Mr. Joseph B. Stearns of Boston had been engaged for several years previous to this date in experiments on simultaneous transmission, or, as he called it, duplex telegraphy. In principle his apparatus did not materially differ from that of his predecessor and contemporaries, and until 1872 his success was not more marked than theirs. Early in this year he introduced the "condenser"[1] into what is known as the "artificial" or "compensating" line, thus overcoming the only serious obstacle to success. The great value of his improvement was quickly appreciated, and to Mr. Stearns is generally accorded the credit of having made the system practically possible. The increase in the use of the telegraph within a few years had been such that a generous welcome was extended to any device which enabled one line to do the work of two; and Stearns's system was rapidly adopted, both in this country and in Europe.

The fundamental principle is, that a compensation or balance shall be established in such a way, that, when the circuit is closed and a current is sent from one end of the line, the instrument at the sending station shall not be affected by that current, while that at the receiving end shall register as in ordinary telegraphy. There are two leading methods by means of which this has been accomplished, — one known as the "differential" method, and the other as the "bridge" method. In the differential method, the current is divided in its course about the electro-magnet at the sending station. It will be remembered, that if a coil of wire be wrapped around a soft iron core, and a current of electricity be passed through it, the core will become a magnet, with its poles arranged in a definite manner, depending on the direction of the current. Suppose two coils of equal length to be wound around the core in such a way that they are similarly situated in regard to it: a current sent through either of these coils will magnetize the core, and, if sent through both coils *in the same* direction, the effect will in general be increased. If, however, the same current is sent through both coils, but in *opposite directions*, the polarity of the core due to one will be the exact reverse of that due to the other; so that they will exactly neutralize each other, and the core will remain practically unmagnetized. This is what is accomplished in the differential system. The current from the battery, which is thrown into the line by the closing of the key, *divides* on entering the coils of the electro-magnet, one part going through the line to the distant station and to the earth there; the other, to earth directly. But in order that the current shall divide equally, so that the home instrument may not respond, the *resistances* offered by the two branches into which it goes must be equal to each other. On the one side the resistances are the magnet coil, the line-wire, and the instruments through which the current must pass at the other end before reaching earth. On the other side is the magnet coil; so that to this must be added a resistance equal to the line and the receiving instrument, before the balance will be complete. This additional resistance is preferably of fine wire; German silver being very commonly used, on account of its high specific resistance. It is introduced between the magnet coil and the earth, occupies but a small space, and is known as the "artificial" or "compensating" line. When the key is closed, the current divides itself equally between these two equal paths, and the instrument at the sending station is unaffected. Now imagine a precisely similar arrangement at the other end, and, for convenience, call one of the operators A and the other B. If A closes his key, half the current from his battery traverses the line, and, going to B's instrument, passes around the core of the electro-magnet so as to cause it to attract its armature and thus register the signal. It is important to observe that this current does not here divide, and run in opposite directions about the core, but that its direction is all the time the same. If B closes his circuit, A's battery being off, the current divides on entering the instrument, producing no action, precisely as it did in the previous case at A's station; and one half of it passing over the line operates A's instrument just as before, for the two ends of the line are alike in every respect.

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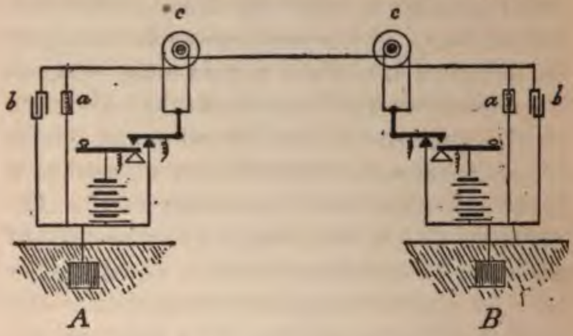
[1] A condenser consists of alternate sheets of tinfoil, with some insulating material, such as mica or paraffined paper, and is in principle precisely the same as the Leyden jar. Beginning on one side, the first, third, fifth, seventh, etc., sheets of foil are joined together, and correspond to one coating of the jar: the remaining sheets of foil are also joined, and constitute the other coating. In this form a condenser may have much greater capacity for electricity, and occupy much less space, than in the ordinary form of the Leyden jar.



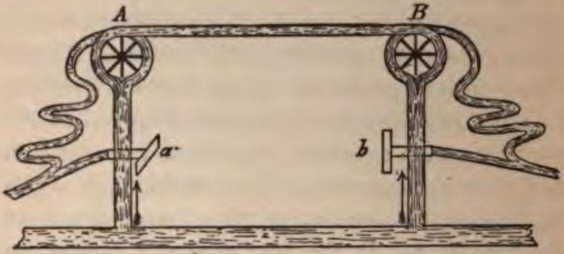
Scheme for duplex telegraphy: *a a*, artificial line or balancing resistances; *b b*, condensers; *c c*, receiving instruments with double winding in opposite directions.

It thus appears, that, when either operator is silent, the other can transmit a signal, precisely as in the ordinary single-message system, except that this signal is not registered on his own instrument, as it ordinarily is. It will be seen that by this arrangement either operator, while unable to make signals upon his own instrument, can produce them at the other end by disturbing the balance which exists there, so that each instrument is always ready to receive and register signals from the other end of the line. On this fact depends the possibility of double transmission; but that possibility may appear more evident upon the consideration of the details of a simple case.

Duplex telegraphy implies that both A and B shall be transmitting signals at the same moment, and each receiving what the other transmits. To understand that the arrangement just described may be made to accomplish this, suppose that both A and B close the circuit at precisely the same moment. One of three conditions may exist, — both may be intending to transmit a dot, both a dash, or one a dot and the other a dash. In the first case, both keys will be closed for the same short period of time, during which currents from both batteries will enter the line; but will they now divide equally at the electro-magnets, as described above? If they do thus divide, both instruments will be silent, and no signal will be received at either station. A little reflection will show that the two equal currents going to the line neutralize each other, so that neither is effective, while the currents which at each end flow around the magnet and to earth through the artificial line, being unopposed, *are* effective; and that the cores are thus rendered magnetic, and signals are recorded at both ends. If these signals were intended to be dashes instead of dots, the action would be precisely the same, except that it would last longer. But it is a curious fact, and worthy of remark, that the signal registered on A's receiver is made by the current from his battery; and, similarly, the signals recorded by B's instrument are produced by the current from his battery.

It only remains to show what will occur when one of the operators desires to transmit a dash, and at the same moment the other wishes to send a dot. Suppose both keys are closed at the same instant: the condition of things is as described above. Now, if B desires to send a dot, he will keep his current on only for an instant; while A, who wishes a dash to be recorded at the distant station, will keep his on for a longer time. While both keys are closed, a dot is made at each station; but, the instant B breaks his current, the condition is that first described above. A's current now divides equally at his instrument, so that it instantly ceases to act; while half of his current goes through the line and to B's receiver, causing it to register, until, having completed the dash, A's key is opened. Thus at A's station a dot has been recorded, and at B's a dash, precisely as was desired. In this case the dot at A's instrument was produced by the current from his own battery; while, of the dash received at B's station, a part equal in length to a dot was produced by the current of his own battery, while the remainder was due to the current sent over the line by A. In this way dots and dashes can be transmitted at will; and, as the alphabet consists entirely of these, simultaneous transmission becomes possible.

To those not familiar with the behavior of electricity, this operation may be made somewhat clearer by the use of a homely illustration. Suppose that two people living in a city supplied with a system of water-works desire to establish telegraphic communication with each other by means of water. Connection between the two points is made by means of a small pipe of iron or other suitable material, into which water from either end can be forced by opening a stopcock. Some device will be needed to show the passage of the current; and this might be a small, inclosed water-wheel, with a suitable index, which is made to turn by the flow of water around it. The essential features of such an arrangement are shown in the diagram.



Scheme for duplex telegraphy by means of water pipes.

The two stations are identical. The stream of water, before entering the box containing the wheel, is divided into two parts, one of which flows around the wheel in one direction and thence into the "line." The other passes round the wheel in the opposite direction, and is emptied through a narrow or crooked pipe. Water is admitted by turning the stopcock *a* or *b*, which differs from the ordinary gas or water cock in that an additional opening is provided; so that when the cock is closed, as *a* is represented, thus obstructing the passage from the street main, water from above, after having passed the wheel, can find an easy exit through the end of the cock to the waste, along with that from the narrow pipe already referred to. The latter by being thin or crooked, offers as much resistance to the passage of the water as does the whole line, with the wheel and stopcock at the distant end. This corresponds to the "artificial line" in the duplex electric-telegraph. The water-wheel, with the divided current flowing about it, is analogous to the "differential relay;" and the stopcock to the "key," which, in one position, allows the passage of the current, and in the other affords free egress of the current from the other station to the "ground." The water-pressure in the street main plays the part of the electromotive force in the batteries of the electrical system. The operation of the whole as a duplex telegraph will need little explanation. The operator at A transmits a signal by opening stopcock *a*. Water rushes in from the main; and, since the resistances offered by the two paths are equal, it divides equally in flowing around the wheel. Equal currents being thus applied to opposite sides of the latter, it remains at rest. Half the current, however, passes through the line, and, reaching the receiving instrument at B, passes around the wheel there on one side, and out through the stopcock *b;* or, if a small part of it passes to earth through the artificial line (and this will always be the case), it goes in such a way as to aid, and not to oppose, the movement of the wheel. Thus a signal will be received at B which will be interpreted as a dot or a dash, according as the time of motion is short or long. Of course, the transmission of a signal from B to A is accomplished in precisely the same way. If both stopcocks are opened at the same moment, it will easily be seen that the two equal opposing currents in the line will prevent any actual flow, and at each end flow will take place only into the artificial line, and signals will be recorded at both. It is also clear, that if the operator at B, wishing to send a dash when only a dot is to be transmitted from A, shall continue to hold his key open after the other is closed, the balance will be at once established at B, the wheel will cease to move, and a dot will be recorded; while the current from B, now flowing through the line, will maintain the motion at A until a dash is registered there.

It has already been stated that duplex telegraphy was not practically successful until after the introduction of the "condenser" by Mr. Stearns. The necessity for its use grew out of the existence of a difficulty which is experienced in a greater or less degree in all electric telegraphy; and, as frequent reference to it will be necessary in the future, it will be desirable to explain its origin and effect in this particular case, as well as the operation of the condenser in removing it.

Every telegraph-conductor, whether suspended in the air, buried in the ground, or submerged in the water, behaves in some degree like a Leyden jar; that is to say, electricity may be stored up in it, the amount depending on what is technically called its "electrostatic capacity." When a current from a battery is sent into a line, a part of the electricity is therefore used in charging the line, while the remainder goes to do the work of making the signals at the receiving end. To recur to the analogy of the water-telegraph, it is evident that the pipe must be filled, or partially filled, before motion of the receiving wheel can be produced. Now, when a line thus charged is cut off from the battery by opening the key, the charge existing on the line will find its way to the earth, at both ends if possible. The effect at the receiving end will be to prolong the operation of the receiving instrument to some extent; but on "overhead" lines this prolongation is generally so slight as not to be a very serious difficulty, except on lines of great length. In the duplex telegraph, however, it is clear that this discharge may take place at the sending end, as connection with the earth exists there. The effect will be precisely as if a current had been received from the other end, and the instrument at the sending end may thus be made to register a false signal. Now, the condenser, in which electricity may be stored, as already described, has one of its poles or plates joined to that one of the two coils surrounding the core of the electro-magnet, which is connected with the artificial or compensating line, and the other to the earth. When a current is turned on, it is charged; and when the current is cut off, it discharges through the coil to the earth. By properly regulating the number and size of the plates, the effect of this discharge may be made to compensate exactly for that of the discharge from the line, since the currents flow in contrary directions around the magnet, and thus a perfect balance is maintained. Referring again to the analogy of the water system, after a signal had been sent from A to B by opening the stopcock, the closing of the cock might be followed by a flow of the water in the line back through the instrument at A, and the production of a false motion of the wheel. But if it could be arranged that an equal flow would take place from the artificial line, this, urging the wheel in the opposite direction, might exactly balance the first, and no signal would be recorded.

The successful accomplishment of simultaneous transmission of two messages in opposite directions, through Stearns's improvements, was quickly followed by another remarkable advance, in which the capacity of the line was again doubled, and the quadruplex system rapidly superseded the duplex. Very soon after the publication of Gintl's scheme for duplexing in 1853, the attention of inventors was drawn to the question of simultaneous transmission of two messages over the same line in the same direction. Numerous methods of accomplishing this were proposed, the earliest of which was probably that suggested by Stark of Vienna in 1855, who also clearly recognized the fact, that, if the thing could be done, quadruplexing would be possible by combining his method with that of Gintl. Much labor was bestowed upon the problem by various inventors, but its complete solution was not reached until after the duplex telegraph had been perfected by Stearns. The principle common to nearly all methods is that of working through the line with two currents differing greatly from each other in strength or character. The two sets of receiving instruments differ in the same way, so that each will respond to one of the two currents only.

Perhaps the most satisfactory and successful method of accomplishing the end is that devised in 1874 by the well-known inventor, Thomas A. Edison. In order to discuss its method of working understandingly, it will be desirable to remind the reader of the construction and operation of the common Morse receiving instrument. In this the signals are produced by the to-and-fro movement of an armature in front of the electro-magnet. This armature is of soft iron, which does not become permanently magnetic, or only very slightly so, and which is attracted by the magnet without regard to the character of its poles; that is to say, the armature will be drawn up whenever a current is passed through the coil of the magnet, regardless of the direction of the current. When the current ceases, the armature is drawn back against its stop by the action of a retracting spring, the strength of which may be varied at will. Its operation, therefore, depends solely upon variations in the strength of the current, and not at all upon its direction.

But it is possible to use what is called a "polarized" or permanently magnetic-armature. This will be attracted by a magnetic pole of the opposite sign, and repelled by one of the same sign; so that to-and-fro movements may be produced by reversing the direction of the current in the coils, which reverses the polarity of the magnet core. The retracting spring is dispensed with, and the working of the instrument is, in general, independent of the strength of the current, being influenced only by its direction. The current is kept on the line constantly, and, by means of a suitably arranged key, a reversal of its direction is brought about by a single movement, and to this reversal the armature instantly responds. Thus there may be two independent receiving instruments, one of which responds to variations in the strength of the current alone, and the other, only to changes in its direction. It is by combining these two that double transmission becomes possible. One operator works with a current of comparatively feeble strength, the rapid reversals of which reproduce his signals on the polarized receiving instrument. When the other closes his key, additional battery is thrown on the line, and the strength of the current is made sufficient to operate the non-polarized receiver at the distant end, the retracting spring of which is so adjusted that it will not respond to the feebler current constantly on the line. This increased current is always under the control of the first operator, who is able to reverse it at will, the reversal operating the corresponding receiving instrument, but producing no effect on the other, which works independently of direction. It is easy to understand that each has entire control over one receiving instrument, and is in no way interfered with by the other, and that only one wire is necessary in the operation. By combining this system with simultaneous transmission in opposite directions, a quadruplex system results, in which, upon a single wire, eight operators are employed, two receiving and two sending at each end. Quadruplex telegraphy has come into very extensive use, and it has enormously increased the working capacity of the telegraph systems of the world.

That multiplex telegraphy should follow would naturally be expected; but its nearest approach to success, thus far, has resulted from an invasion into new territory, rather than from the development of the principles involved in duplex and quadruplex transmission. Very many methods have been proposed for transmitting over a single wire a large number of messages at one time. Some of them have been tried, and, at least temporarily, rejected. Others have been maintained in practice for some time with more or less success, but may still be considered as "on trial." The general principles involved in two or three of the most interesting systems will be considered: others are, to a great extent, modifications of these.

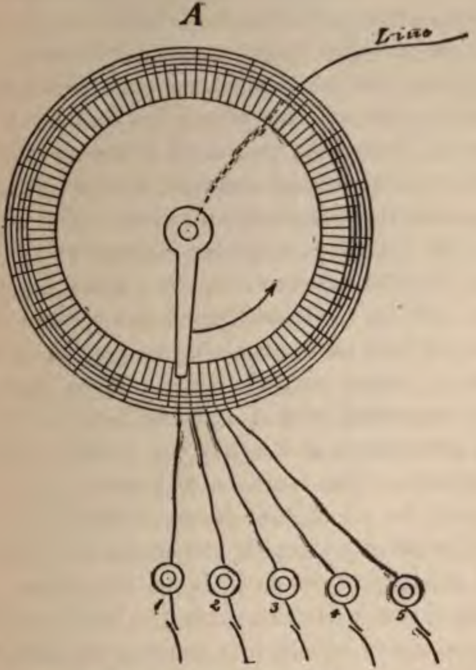
Although not the earliest in point of time, one of the most important of these, on account of the results which have come from its development, is what is known as the "harmonic telegraph." This has been made the subject of investigation in this country by Gray, Bell, Edison, and others, but as a system of multiplex telegraphy it has been most nearly perfected through the labors of Gray.

The fundamental principles of its operation may be understood without great difficulty. In the first place, it depends upon the possibility of transmitting electric impulses through the line with such rapidity, that an armature, moving in response to these impulses, will vibrate with a frequency sufficiently great to produce an audible musical tone. There is required a transmitter, by means of which the electric impulses are thrown into the line, and a receiver, by means of which they are reproduced as a musical tone at the other end. The transmitter may be a steel rod or reed, rigidly fixed at one end, with the other free to vibrate. In this condition it will have a definite period of vibration, precisely as has a tuning-fork or a piano-string; and the number of vibrations it makes in a second will be almost entirely independent of its amplitude. Its motion may be maintained by means of a local current and an electro-magnet; the latter being placed near to it, but not in contact with it. If the current flows, the electro-magnet being excited, the reed will be drawn aside, where it would remain, were it not so arranged that the reed itself, forming or controlling a part of the circuit, breaks the circuit as soon as it moves slightly from its position of rest, and the magnet ceases to act upon it. In virtue of its elasticity, it returns to and beyond its normal position, thus closing the circuit, upon which the operation is repeated, and the reed is kept in motion with nearly a natural frequency. It is only necessary to make this reed act as a key in the main line circuit, to transmit electric impulses with a frequency corresponding exactly with its own. The introduction of an ordinary key, by means of which the main circuit is made and broken at will, enables the operator to throw the rapid succession of impulses into the line as he would an ordinary steady current. The receiver consists of a reed similar to that used as a transmitter, and vibrating with the same frequency. It is influenced by an electro-magnet placed near it, through which the intermittent or vibratory current passes.

Now, if the number of vibrations per second of the first or transmitting reed is 300, and if the receiving vibrates naturally at the same rate, it is clear that the latter will vibrate under the influence of the electro-magnet, whenever the transmitter is controlling the line current. It is also evident that a good degree of synchronism must exist in the two vibrating reeds, in order that the vibrations may be reproduced. If their periods are identical, whenever the transmitter throws a current into the line, which it does at a definite instant in each vibration, the receiver will be in a position to be favorably acted upon by the electro-magnet then excited. If, on the contrary, the two do not vibrate alike, it will frequently occur, that, when the receiving reed is drawn by the magnet, it is being urged in the opposite direction by its own elasticity, and its motion may then be nearly destroyed. Imagine, now, that two transmitters and two receivers are connected to the same line, and that the vibration frequency of one set is 300 per second, while that of the other is 500. When both reeds are connected to the line, a series of impulses will be transmitted, compounded of these two frequencies, resulting in a sort of composite fluctuation in the current strength, similar in many respects to the fluctuations in the density of the air, when transmitting two sounds differing in pitch. But the receiving reeds possess the power of analysis and separation. If the vibration frequency of 300 is present in the composite, the reed tuned to that number of vibrations per second will respond to it, and the same is true of that whose vibration frequency is 500 per second; but neither will respond when the vibrations corresponding to the other are alone transmitted. By manipulating the keys at the sending station, the continuous tones may be broken up into "short" and "long," or dots and dashes; and each operator at the receiving station has only to attend to these interruptions in the motion of his own reed. But the number of pairs of vibrating reeds is plainly not limited to two; several more may be employed, and the number of messages simultaneously transmitted increased; and this system may also be combined with the duplex, as has been done by Mr. Gray, with excellent results.

Numerous attempts have been made to accomplish multiplex telegraphy by means of the synchronous motion of cylinders, disks, etc., at the ends of the line. The production of two motions which shall be rigorously synchronous is, of course, practically unattainable. Unfortunately the applications of this principle to telegraphy demand a degree of approximation to perfect synchronism which has been found difficult to realize; but a considerable advance seems to have been made recently by Mr. P. B.

Delany, whose multiplex telegraph, based on the synchronism of two revolving arms, has attracted much attention within the last two or three years.



Distributing disk for multiple telegraph by means of synchronous rotation.

The principle of this form of multiplex working is exceedingly simple.

A single wire connects the two stations, and at each end is a distributing wheel. A flat, circular disk of wood or other insulating material is provided with radial metal strips let into its surface, not extending to the centre, and insulated from each other. There may be any number of these strips, say, one hundred in all. Suppose that it is desired to work five distinct circuits over one line wire: the first strip will then be joined, by means of a copper band or wire running around the disk, to the sixth, the eleventh, the sixteenth, and so on. The second will be joined in a similar manner to the seventh, twelfth, seventeenth, etc.; and this operation will be continued until five groups have been formed, each containing twenty wires electrically joined to each other. Each group is then connected with a suitable relay or receiving instrument and a key, as in an ordinary telegraph. The same battery may supply the current for all of the circuits. Moving about an axis passing through the centre of the disk, and at right angles to it, is an arm which connects through the axis with the line, and upon the outer end of which is a spring contact-piece which presses lightly upon the face of the disk, so that by the rotation of the arm this spring touches successively upon each of the radial strips described above, and thus puts each group of them, one after another, in connection with the line. During one revolution of the arm, any one group, with its receiver and key, will be electrically connected with the line twenty times; and, if the arm is driven at the rate of three revolutions per second, such connection will exist sixty times in that interval of time. Now, imagine a precisely similar apparatus at the other end of the line: call the two station A and B, and the circuits No. 1, No. 2, etc. If the movements of the two revolving arms at A and B are absolutely synchronous, it will be easy to arrange so that circuits No. 1 A and No. 1 B will be in electrical connection with each other through the line sixty times in every second; similarly, No. 2 A and No. 2 B will be joined sixty times per second; but at no time will No. 1 A be in communication with any other than No. 1 B, nor will No. 2 A ever be connected with any other than No. 2 B; and so on with all of the five circuits.

It has already been shown, in the consideration of Gray's harmonic telegraph, that a continuous current is not essential to the working of a telegraph system; and it is found, that with an ordinary Morse receiving instrument, if the breaks in the current occur with sufficient rapidity, the effect is similar to a continuous but weaker current. In the present instance currents are transmitted through each circuit at the rate of sixty per second, and this would enable the operators to work with each other with nearly the same ease as if the current were continuous. The number of circuits may be considerably increased; and, in fact, as many as seventy-two have been provided for in some of Mr. Delany's instruments, and have been successfully operated.

As thus far described, the system is really nothing more than that suggested by Farmer in 1852. The same principle has been worked over by many other inventors since that time, but the real difficulty has always been the seeming impossibility of maintaining synchronism of motion at the two ends with a sufficient degree of approximation. Although he has improved the method in many of its details, it is in surmounting this difficulty that Mr. Delany has been most successful. The mechanism made use of for this purpose is somewhat complicated, and it will be desirable to consider it only in a general way.

The nearest approach to synchronism of motion which is suitable for this purpose, is found in two vibrating reeds, or tuning-forks, carefully adjusted to agree with each other in pitch. Accordingly the revolving arms are driven by electric motors, the operation of which is controlled by vibrating forks. For this purpose the electro-magnets of the motor may be excited by currents which are regularly thrown on by the vibrating fork, as was explained in the discussion of the harmonic telegraph. But the vibration period of a tuning-fork is influenced by the temperature to which it is subjected; and it is found that, however perfectly two forks may be made to agree at one place and time, they cannot be depended upon to be perfectly synchronous when separated from each other, and under different conditions. Without some method of correction, the revolving arms would soon stray away from synchronism, and dire confusion in the communications would result. To surmount this difficulty, Mr. Delany has introduced extra radial strips in the distributing disk, which are not connected with any of the branch circuits. They are arranged in such a way that, as soon as one arm gains a little upon the other, a correcting current is thrown into the line, which, by its effect upon the magnets of the motor, reduces the speed of that which is in advance, and thus a sufficiently approximate synchronism is maintained.

This system is well suited for the distribution of telegraph facilities in the neighborhood of the terminus of a main line. A dozen or more business men in New York may be connected with as many correspondents in Boston through one line connecting the two cities. As the number of branch circuits increases, the rapidity of transmission diminishes; but, in what may be called "private telegraphy," speed of working is generally not of primary importance. It is stated that a line between Boston and Providence, on which Delany's system was used, worked at the rate of forty words per minute over each of six separate circuits; when divided into twelve, the rate was reduced to twenty words per minute; and that seventy-two printing circuits were worked at the rate of from two to three words per minute.

In the application of electricity to the transmission of signals through submarine cables, so many modifications of the methods already described are found necessary, that the subject of submarine telegraphy is worthy of special consideration. Although at the present time the laying of a cable, even across one of the great ocean-beds, is a mere business matter, involving only the expenditure of a certain amount of money, it has become so only after a vast number of failures and the loss of an immense amount of capital feebly represented by the material lying useless at the bottom of the sea. The conditions necessary to success were not at first understood; for, in the earlier years of cable-laying, it was not considered necessary or desirable to utilize the knowledge and skill of scientific electricians of the first rank. Success was finally reached only after such were induced to study the complex problems involved. The lesson was costly but unavoidable.

The attempt to lay insulated conductors under water naturally followed upon the practical introduction of the telegraph. Covered with hemp or cotton, which was saturated with tar, asphaltum, or other insulating materials known at the time, they soon lost their insulation, often after only a few days' exposure. Owing to the great importance of being able to connect land lines across rivers and lakes, every effort was made to discover a suitable material for insulation, and it was even proposed to use short glass tubes connected together by universal joints, to give flexibility.

While various materials were being tried, an English surgeon, stationed at Singapore, was experimenting upon the properties of a substance which was destined to afford the solution of the problem. In 1842 he recommended gutta-percha as useful in making splints and other surgical appliances, and shortly afterward forwarded specimens of the substance to the Society of Arts in London. It soon attracted the attention of the commercial world, and numerous patents for its preparation were taken out. One of its most striking properties is its high insulating power; and its value as a covering for submarine conductors was soon recognized. During the past forty years innumerable attempts have been made to discover something which will take its place, but without great success. It is extremely probable that the wide-spread use of submarine cables would have been postponed many years, had this substance remained unknown. One of the first cables insulated by this material, and possibly the very first, was laid in 1848 across the Hudson River, from Jersey City to New York. In 1850 a cable was laid across the Channel, from Dover to Calais; but it was unprotected by any sheathing or armor, and it lasted but a single day.

In the following year the experiment was repeated, this time with a cable protected by a number of heavy iron wires. The operation was successful, and permanent telegraph communication was established. During the next few years the number of submarine cables increased rapidly, as did also their length, although, on account of ignorance in regard to many conditions necessary to insure the best success, failures were numerous. Many people began to consider the feasibility of a line connecting the continents across the Atlantic Ocean. A few sanguine capitalists combined to further the enterprise, and through the undaunted courage and faith of an American, Mr. Cyrus W. Field, the purely financial obstacles were surmounted. Unfortunately the electrical and engineering problems to be met with were not understood; and the memorable first cable of 1858, after gasping for breath for a few short weeks, lay dumb forever at the bottom of the sea.

Something of the character of this cable may be learned from the following brief description by Sir William Thomson, to whom, more than to any other one man, the world is indebted for the success of submarine telegraphy: —

> In the year 1857 as much iron as would make a cube of 20 feet side was drawn into wire long enough to extend from the earth to the moon, and bind several times around each globe. This wire was made into 126 lengths of 2.500 miles, and spun into 18 strands of 7 wires each. A single strand of 7 copper wires of the same length, weighing in all 110 grains per foot, was three times coated with gutta-percha, to an entire outer thickness of .4 of an inch; and this was "served" outside with 240 tons of tarred yarn, and then laid over with the 18 strands of iron wire in long, contiguous spirals and passed through a bath of melted pitch.

An attempt to lay this cable in 1857 resulted in the loss of 400 or 500 miles, by breakage from the stern of the ship from which it was run. After some further experimentation, it was determined to employ two ships to lay it in the following year; and accordingly, on the 29th of July, 1858, the Niagara and the Agamemnon, each loaded with half the cable, met in mid ocean, joined the ends, and started, the Niagara for the West and the Agamemnon for the East. On the 5th of August the ends were successfully landed on the opposite shores of the Atlantic.

The cable was known to be in bad condition before the laying was completed, and the earnest but ill-advised efforts which were made to force it to work during its brief period of activity, only tended to shorten its life. Communication of a very irregular and unsatisfactory character was maintained for several weeks. The admirable mirror galvanometer, which had just been devised by Sir William Thomson, was for the first time in use at the Valentia end, while for a time the attempt was made to use the ordinary receiving apparatus, which had been provided by the company at Newfoundland. The result of this was that signals were received with little difficulty at Valentia, while much trouble was experienced at Newfoundland. Later the mirror galvanometer was put in use on this side, but not before very powerful currents had been used on the cable, tending to increase existing faults. In fact, Sir William Thomson has declared his belief, that, if proper methods of handling the cable electrically had been in use from the beginning, its performance would have been lasting, and in the main satisfactory.

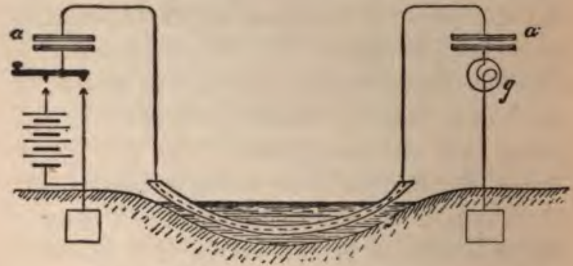
Owing to the fragmentary character of many of the messages transmitted, a single sentence from that of the Queen to the President having been received on August 16, and the remainder twenty-four hours later, many persons in both Europe and America became sceptical as to the transmission of signals, and not a few even doubted that the cable had been laid. As a matter of fact, four hundred messages, containing over four thousand words, were sent. On September 1, interchange of messages ceased; but on October 20 the cable spoke its last words, — "two hundred and forty," — which were read at Valentia, being part of a message giving the number of battery-cells then on the line. From that date the "splendid combination of matter lay at the bottom of the sea, forever useless." But it had not lived in vain: the possibility of the thing was demonstrated, and it only remained to surmount certain obstacles, the existence of which this trial had proved.

During a few years succeeding this first attempt, the problem was studied in the light of the experience which it had afforded. Another trial was made in 1865, this time by the Great Eastern, a vessel which offered many advantages for cable-laying. After about two thirds of the distance was run the cable broke, and further operations were postponed until the following year, when a complete cable was successfully laid, and that of 1865 picked up, spliced, and finished. Since then other lines have been placed across the Atlantic; and now the operation of laying an ocean-cable attracts no attention, save from those who are directly interested in the enterprise.

In the construction of a cable, it is essential that the wire which is used as a conductor should be surrounded by a sufficient thickness of as perfect insulating material as is available. A line suspended in the air may be insulated with comparative ease, for the medium by which it is surrounded is itself an almost perfect non-conductor. The conducting power of water, however, is extremely high, compared with that of air, and the water in which the cable lies must nowhere come in contact with the copper conductor. The cable must also possess sufficient strength to survive the operation of laying, and to be uninjured by whatever disturbances it may be subjected to when in place.

Consisting, as a cable does, of a long conductor surrounded by a thin layer of insulating material, and then again by a conductor, it is electrically similar to a great condenser, or Leyden jar, as was observed by Faraday in connection with some of the earlier short cables. Reference has already been made to what is called the "static capacity" of a land line: that of a cable of the same length is generally many times as great. If a well-insulated wire, a few hundred or a thousand feet in length, be coiled in a vessel of water, with one end projecting into the air or sealed over with gutta-percha, the current from a single battery-cell, in rushing in to charge the wire, will cause a violent deflection of the needle of a sensitive galvanometer. A considerable length of time will be consumed in completely charging a cable, and, of course, time will be occupied in discharging it. The result of this is a great retardation of signals and a correspondingly less speed of transmission. It is said, that, if the attempt were to be made to use ordinary Morse instruments on one of the Atlantic cables, hardly more than one word per minute could be transmitted. The signals are not only retarded: they are altered in character, becoming less sharp and distinct as the length of the cable increases.

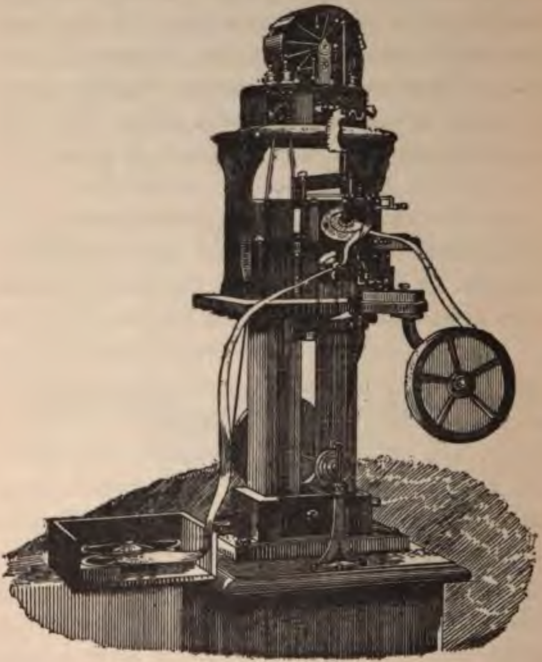
As already remarked, the use of strong currents is extremely objectionable, and thus there are several reasons why ordinary methods of operating prove insufficient when applied to ocean cables. Scarcely any modification is required in the sending apparatus: a single key for closing the circuit may be used, or a double key, by means of which either positive or negative electricity may be sent to the line. It is found to be advantageous, however, not to connect the battery with the line at all; that is to say, not directly, but only indirectly through a condenser, one branch of which is connected with the line, and the other with the earth through the battery, key, and receiving instru-



Ocean cable system; *a a*, condensers; *g*, galvanometer or receiving instrument.

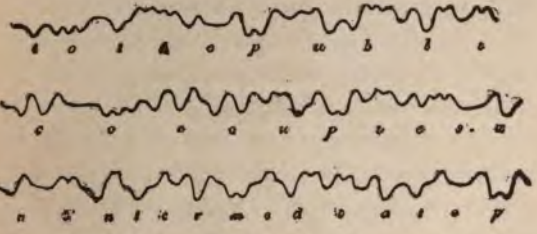
ment. The condenser is prepared by insulating sheets of tinfoil from each other, as already described. The surface of foil used in one of these condensers is only slightly less than one acre, although it occupies a space of less than three cubic feet; and, for the purpose of "duplexing" the cable, a condenser of more than two acres of surface has been used. The use of a condenser increases the speed of transmission, besides offering other advantages. The signals are received by an extremely sensitive galvanometer, devised for the purpose by Sir William Thomson, to which reference has already been made. In this the wire is very fine, and the number of turns very great. The needle is extremely small, consisting of several short magnets fastened to the small circular mirror, the whole often weighing less than half a grain. This needle is suspended by a single fibre of silk in the centre of the coil, which is wound as closely to it as the necessary freedom of motion will allow. A beam of light falls on the mirror, and is reflected upon a screen, where a spot of light is seen. The movements of the needle are indicated by and magnified in the motion of this spot, and the alphabet is made up of to-and-fro movements.

This beautiful instrument has been used on many cable lines, but it has been largely superseded by the "siphon recorder," devised by the same distinguished electrician. In this a light, rectangular coil of fine wire is suspended between the poles of a powerful electro-magnet. Advantage is taken of the fact that a coil of wire through which a current is passing tends



Thomson's siphon recorder for ocean cables.

to place itself in a particular position in a magnetic field. A fine glass siphon tube is attached to the coil, and moves with it. The short arm dips into a vessel of ink, which is insulated and capable of being electrified. The long arm has its open end very near to a small plate or table, over which a strip of paper is moved regularly by clock-work, as in the Morse register. The whole system (tube and coil) moves with great freedom, and is deflected from its normal position by very feeble currents. The electrification of the ink causes it to be projected from the end of the tube in minute drops, so that the movements of the coil are recorded on the moving slip of paper in very fine dots very near to each other. An actual record of the message is thus made, which can be read at leisure and preserved. As noticed by Mr. Prescott in his valuable work on the telegraph, it is curious to



Specimen of message written by siphon recorder.

see, that, in the evolution of telegraphic methods, that feature of the Morse system which was at first thought to be of the highest importance, namely, its capacity for recording the message on paper, has been almost wholly discarded in practice; while the needle telegraph, which in the beginning made no record, now finds almost its only representative in the siphon recorder.

CHAPTER VI.

FARADAY'S DISCOVERY OF INDUCTION AND THE DEVELOPMENT OF THE DYNAMO.

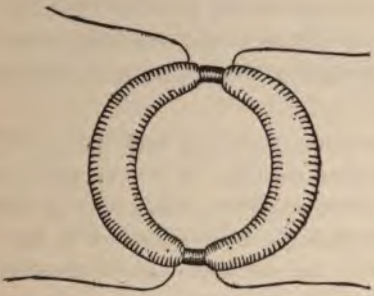
AMONG innumerable contributions to the world's knowledge of electricity, three splendid discoveries stand incomparably above all others. More than all others, these opened new fields for research, and created new possibilities of application. The discovery of the "new electricity" by Galvani, and of a means of generating it by Volta, and Oersted's memorable experiment in which its influence upon the magnet was revealed, have already been described. Magnificent results which have sprung from these two discoveries have been briefly considered, although it cannot justly be affirmed, that, in their development, nothing has been due to the third member of the triad. But the catalogue of the accomplishments of human genius, as worked out along the line of electricity, would be very incomplete if terminated at this point. Nearly all of the more recent and more striking applications of the electric current, in which almost daily it is being made to serve man in some new capacity, rest upon the last of the three great discoveries, — that of electromagnetic induction, by Faraday.

The son of a blacksmith, for a time a newspaper-carrier, a bookbinder's apprentice at the age of thirteen, Michael Faraday, as a youth, enjoyed few facilities for the acquirement of an education. In a common school he learned the rudiments of reading, writing, and arithmetic; but his apprenticeship, which lasted for eight years, afforded some opportunities for satisfying his keen thirst for knowledge. He eagerly devoured scientific literature which fell in his way, and his attention was especially drawn to electricity by the perusal of an article in an encyclopædia which he was employed to bind. A customer of his master's shop, who was a member of the Royal Institution, afforded him the opportunity of attending four lectures on chemistry, given by Sir Humphry Davy in 1812. Of these lectures he made an admirable series of notes. These he neatly transcribed, illustrated, and sent to Davy, with the request that he might be given some employment in the Royal Institution which would enable him to indulge his taste for experiments and study. To this Davy replied, praising the notes, and promising an interview. At that interview he advised young Faraday to stick to his bookbinding, and "promised to give him the work of the Institution, as well as his own, and that of as many of his friends as he could influence." Shortly after this, however, Davy dismissed his assistant, and, remembering Faraday's desire, he employed him to fill the place. Thus at the age of twenty-two years, and under these not very promising circumstances, he began a career which, for usefulness as well as brilliancy, has perhaps never been eclipsed.

Before entering Davy's laboratory, he had experimented largely in electricity; but, almost of necessity, for several years afterwards, his attention was mostly given to questions of a chemical nature, and indeed, as he declared himself, he was "for nearly twenty years a student," during which time he was laying the foundation for the remarkable series of researches which he afterward carried out.

Reference has already been made to his success in producing continuous rotation of a conducting wire around a magnet, and also the reverse. A little later, about the year 1825, the scientific world was puzzling over an experiment by the famous Arago. It consisted in rotating a copper or brass disk underneath a freely suspended compass-needle: the latter was deflected, and might, indeed, be made to rotate about the axis of suspension, provided the metallic disk was turned with sufficient rapidity. No one was able to offer a satisfactory explanation of these rotations; but Faraday conceived the idea that they were due to electricity *induced in the revolving disk*, and so recorded his belief in his note-book. Even earlier than this he was convinced, that, as an electric current affects a magnet, and may even produce magnetism, a magnet, in turn, must be capable of exerting an influence upon an electric current; and from 1825 he occupied himself more or less in the experimental study of the question. He failed to discover anything like an induction effect, and he failed again and again during the next few years. The subject was again taken up in 1831, and on the 29th of August he began that wonderful series of experimental researches in electricity which at once placed him in the front rank of living philosophers, and established his position as the finest experimentalist of the present age.

Faraday's failures arose from the very natural belief that induction in "voltaic" electricity ought to resemble the induction so long known, which occurs when a body charged with electricity is brought near an insulated conductor, in which case a permanent state of electrification is set up. Again: as an electric current passing through a conductor produces a permanent deflection of a magnetic needle, that is, a deflection which lasts as long as the current flows, it is natural to infer that, if the presence of the magnet produces a reactive effect upon the current, that effect will last while the magnet is present. That generalization known as the principle of the conservation of energy, which has since been established, and to the proof of which Faraday himself contributed so much, shows that neither of these things could happen. But what Faraday afterwards pronounced to be "the highest law in physical science which our faculties permit us to perceive," was then but dimly outlined in the minds of a few men, and could not be depended upon, as now, to put a check upon hypothesis.



Faraday's ring; from cut in Phil. Trans. 1832.

Knowing that magnetism was produced from electricity, he attempted to produce electricity from magnetism. For this purpose he used an iron ring about which two or three helices of wire were wound. A current being passed through one of them, the ring became magnetic, and he looked for the production of a current of electricity in the other helix. To detect this current, he connected the extremities of this helix with the poles of a galvanometer.

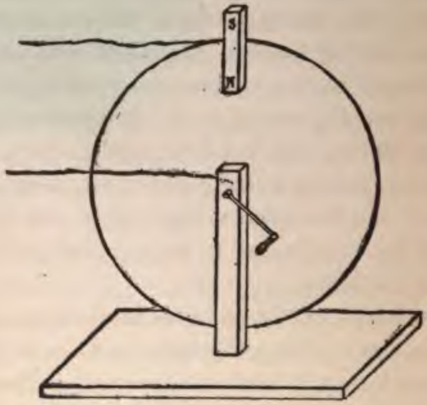
The faculties which enabled Faraday to turn a series of failures into success, as he did on this occasion, are thus aptly described by Tyndall: —

> He united vast strength with perfect flexibility. His momentum was that of a river, which combines weight and direction with the ability to yield to the flexures of its bed. The intentness of his vision in any direction did not apparently diminish his power of perception in other directions; and when he attacked a subject, expecting results, he had the faculty of keeping his mind alert, so that results different from those which he expected should not escape him through preoccupation.

Thus, although expecting permanency of effect, failing to get it, he did not allow the *momentary* movement of his galvanometer to escape his attention. Indeed, he soon discovered that this was the effect for which he was search-ing; that a momentary current was produced in his coil when the ring was made magnetic, and another when its magnetism ceased. He developed and expanded his experiments with wonderful rapidity, and was soon able to produce electricity from magnetism at will. By using bits of charcoal or fine wire, lightly in contact at the extremities of his secondary helix, and jarring them a little at the moment of the passage of the current, so that separation took place, he was able to produce a spark. This, to many, was the most striking evidence of his success in getting electricity from magnetism; and the general interest in the subject caused the experiment to be repeated under various conditions.

Faraday at once saw in these phenomena the explanation of Arago's rotations, believing that the metal disk, when revolved under the magnetic needle, was the seat of induced currents, which, by their reaction on the needle, caused it to deflect. On October 28, he mounted a disk so that it could be revolved between the poles of an electro-magnet, and connected the axis of the disk and its edge with his galvanometer. When the disk was turned, the needle moved, showing the presence of induced currents. This was the first dynamo-electric machine, the parent of all that are to-day flooding with light the cities and towns of the civilized world.

In the mean time he endeavored to induce a current by means of a current, without the use of a magnet. Here again, after many failures, he was successful. The results of his work from August 29 to November 4, during which time only ten days had been spent in actual experimenting, he collected into the first series of "Experimental Researches," presented to the Royal Society on November 24. This paper contains all the general propositions pertaining to electro-magnetic induction, and in its preparation his "rate of discovery" can only be



The first Dynamo.

compared with the work of Ampère following his receipt of the news of Oersted's experiment. It was followed by other papers, in which, in connection with the first, a new and rich field of research was opened to electricians. Faraday's discoveries during these few months, from both the scientific and the practical stand-point, must rank with those of Galvani and Volta in discovering current electricity, and providing the means for its production. Indeed, his discovery might have been made had the existence of current electricity and the battery been entirely unknown; and all of the modern applications of electricity might have followed. As a matter of fact, the method of generating electricity which he first gave to the world, in addition to supplying new demands which it itself created, is rapidly being substituted for the voltaic battery, although it is not likely ever to entirely take its place.

The fundamental principles of electro-magnetic induction, as discovered by Faraday, may be thus briefly stated, and almost in his own words: —

1. When an electric current is passed through one of two parallel wires, it causes at first a current in the same direction in the other; but this current is only momentary, notwithstanding the inducing current is continued. When

this current is broken, another current is produced in the wire under induction, of about the same intensity and momentary duration, but in the opposite direction to that generated at first.

2. If a coil of wire whose ends are joined, through a galvanometer or otherwise, so that a current can pass, be brought up to a magnet, or if the magnet be made to approach the coil, a current will pass through the coil. This current will not be permanent, but will exist only during the motion of approach. If the magnet and coil be separated, a current will again be induced, but, as in the previous case, its direction will be opposite to that of the first.

In endeavoring to express the conditions under which induction takes place, Faraday introduced the conception of "lines of force," being lines along which a free magnetic pole would move, which has since played so important a part in the theory and literature of electricity and magnetism.

Doubtless no one appreciated the value of this work more than Faraday himself, although he failed to protect his right in it by letters patent. It was easy to foresee the immense value of the numerous applications which might be made of his discoveries, but, after having laid the foundation for the electricity of the future, he left its development to others. "I have rather been desirous," he said, "of discovering new facts and new relations, than of exalting those already obtained, being assured that the latter would find their full development hereafter."

The general principle which he had established was that mechanical energy might be converted into electricity in motion, which, indeed, was but another form of energy, capable itself of being reconverted into other varieties; for he had shown that a current of electricity could cause motion in a mass of matter, and that the movement of a mass of matter could produce an electric current. In his experiments, it was only while work was being done that the current flowed; but it was not then as clearly recognized as at present, that a real expenditure of work was necessary to move a magnet towards or away from a coil of wire, that is, work in excess of that required to make the movements in relation to a coil of rope or other non-conducting material. This work is the equivalent of the energy of the electric current, and, in his experiments, was so small as not to be perceptible *except as an electric current.* When he turned his copper disk between the poles of an electro-magnet, he did not observe that it was more difficult to move than when the magnet was absent, although that is really the case;

an apparent "friction against space" existing when the magnet is present and a current is being produced. This friction may raise the temperature of the moving conductor, precisely as if it were ordinary friction, as was first shown by Joule.

In order to understand more fully the conditions under which induction takes place, it will be necessary to recur to the simple laws of electro-dynamics, as discovered by Oersted and Ampère. It will be remembered that Oersted found that a current of electricity passing through a conductor in the vicinity of a magnet tends to move the north pole of the magnet in a certain definite direction; and that Ampère discovered that two parallel conductors attract each other when traversed by currents in the same direction, but repel each other when the currents are in opposite directions. In 1833, Lenz, a Russian philosopher, announced the simple and beautiful law, that currents induced either by the motion of a conductor traversed by a current, or by the motion of a magnet, are always in such direction *as to produce forces opposing the motion generating them.* To overcome these opposing forces, the expenditure of energy is necessary, and this energy is the equivalent of the currents generated.

The problem the solution of which Faraday bequeathed to others was to construct a machine by means of which electricity could be produced in sufficient quantities to be useful, and in which the largest possible percentage of the total energy consumed should be converted into available electric currents, and as little as possible lost in friction and in heat arising from non-available currents. Fifty years have been spent in eliminating the difficulties in this problem, but at the present time its solution is astonishingly near perfect. During these fifty years, innumerable inventors, in both the old and the new world, have contributed to the development of Faraday's principle; and it will only be possible to refer to a few of the principal advances that have been made from time to time, and which have combined to give the dynamo-electric machine of to-day a nearly ideal efficiency.

Perhaps the first realization of the new principle was in a machine devised by Pixii of Paris in 1832. It consisted of an electro-magnet of the horseshoe form, the wire of the coil being long and fine; and of a permanent steel magnet, also of the form of a horseshoe, so arranged that it could be rapidly rotated about an axis parallel to its length, and in such a manner that its poles passed, at each revolution, very close to the poles of the electro-magnet. The soft iron cores of the latter were thus rendered magnetic for an instant by induction, reaching their maximum strength when the poles of the revolving steel magnet were nearly opposite. The rapid changes in the intensity and character of this magnetization induced currents in the coils, first in one direction, and then in the other. The extremities of the coils were joined to the external circuit, and currents were made to pass through that circuit in the same direction by means of a device called a "commutator," which, in some form or other, appears in nearly all modern machines. The simplest arrangement for a commutator, and the form used in Pixii's machine, consists of a brass cylinder revolving on the axis of the rotating magnet, which is divided symmetrically into two parts insulated from each other. Metal springs, connected with the ends of the coils of the electro-magnet, rest with slight pressure against this cylinder, as do also similar springs connected with the external circuit. These springs, and parts of the divided cylinder, are so arranged, that, when the rotation of the magnet reverses the direction of the current in the coils, it also reverses the connection between the contact springs belonging to the electro-magnet and those attached to the external circuit; and thus the current, though discontinuous, is always in the same direction in that circuit.

Saxton improved upon this by rotating the coils instead of the magnet, on the principle that the lighter part should be the moving part. A London instrument-maker named Clarke introduced many modifications into the machine, and especially in the method of winding the coils, finding that very different electrical effects could be produced by varying the length and thickness of the wire. He was probably the first to distinguish between what is now technically known as winding for "tension" and for "quantity;" that is to say, for machines of high or low electromotive force.

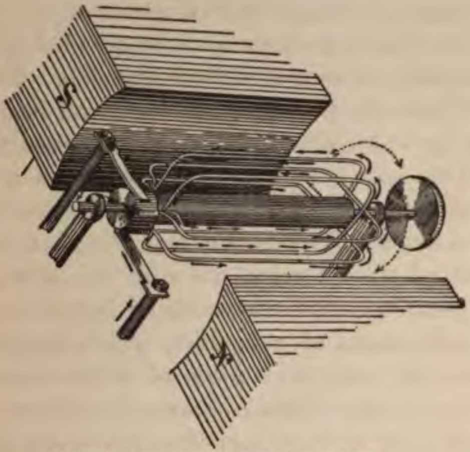
The earliest discoveries of some of the phenomena relating to induction were made by Charles G. Page, a young physician of Salem, Mass. At the age of ten years he had constructed an electrical machine, and soon after his graduation from Harvard University he devised a magneto-electric machine, which differed in form and somewhat in principle from those already described. He placed coils of wire about the poles of a permanent steel magnet which was fixed in position. Variations in the strength of the magnetic field were produced by rotating a soft iron armature before and very near these poles. The weight of the moving part of the machine was thus diminished, and the strength or character of the current produced could be easily regulated by adjusting the distance of the revolving armature from the poles of the magnet.

Both Clarke's and Page's machines are still very common. The effects produced by them are generally very feeble; but, when they are properly wound, currents of considerable electromotive force can be generated. They soon came into general use for medical purposes; and, in fact, no method of producing electricity has yet been devised which has not been assumed to furnish a current of peculiar value as a curative agent. The use of these machines for this and similar purposes has greatly lessened since the invention of the induction coil, the earlier forms of which must also be attributed to Page. They are still very generally used, however, as convenient substitutes for the voltaic battery, especially in the transmission of signals, as in the ordinary call-bell of a telephone system. Other forms of magneto-electric machines, not differing greatly from Clarke's, appeared during this period; but all were small in dimensions, and, generating little electricity, their applications were limited.

At last, in 1849, Nollet of Brussels undertook the construction of a Clarke machine on a large scale, combining many coils and magnets. At first an attempt was made to maintain constancy of direction of current in the external circuit by commutating, as in the simpler forms of Clarke machines. After many failures, this was given up, and the machine was converted into one giving alternate currents. In this method of working, the current in the external circuit is reversed as often as it is in the revolving coils, which, in some machines of this class, is as often as one hundred times per second. For many purposes, however, such a current is as useful as one continuously in the same direction. An Anglo-French company, known as the *Compagnie de l'Alliance*, was formed to carry out Nollet's ideas, from which fact the generator has been known as the Alliance machine. It is said that this machine was at first intended to form a part of a chimerical project to obtain oxygen and hydrogen in large quantities by electrolysis, these gases to be afterward utilized in the production of heat and light. The amount of heat expended under the boiler of the engine which ran it exceeded so much that which could be obtained at the paying end of the machine, that the company soon failed, and deservedly. Its re-organization, for the purpose of manufacturing machines for electric lighting, was an event of real importance in the history of that industry. It was demonstrated that a powerful current of electricity could be generated by induction, and that electric lighting by this method was possible, if not profitable.

Up to this time the battery had been looked upon as the only means of producing powerful currents, and there was no good reason for believing that the battery could ever be made a convenient and economical source; so that the practical utilization of strong currents did not appear to be close at hand. One of the forms of this machine, designed by Holmes in 1856, was submitted to the English Light-House Board, with a proposal for its introduction into light-houses. After severe tests, in which Faraday himself participated, the machine was declared satisfactory, and it was permanently installed in 1862. Others were introduced in France; and, although great improvements were seen to be possible and necessary, their success was such as to encourage inventors everywhere in the belief that the difficulties were not insurmountable.

A very considerable advance was made by Dr. Werner Siemens of Berlin, in the invention, in 1856, of what is known as the "Siemens Armature." Recognizing the importance of rotating the coils in a magnetic field of the greatest possible intensity, he planned the armature as a means of accomplishing this end. It consisted of a long cylinder of soft iron, in which two parallel longitudinal slots were cut at opposite extremities of a diameter. In these slots the wire was wound, thus forming a long and



Skeleton armature of the Siemens type.

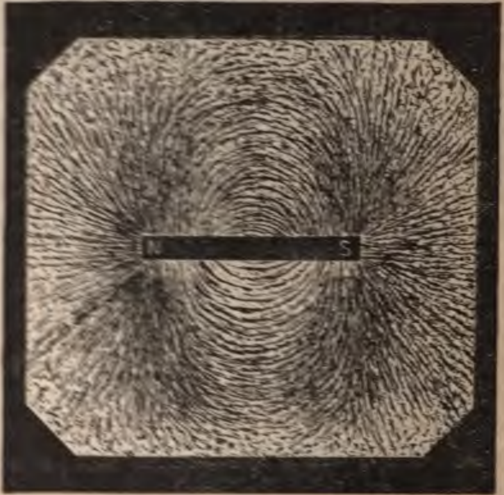
narrow coil, which could be rapidly rotated between the opposed poles of a magnet or of a series of magnets. This form of armature, with slight modifications, is found in many of the best modern machines.

In all of these machines the magnetic field was produced by permanent steel magnets. It is easy to make an electro-magnet of vastly greater power than that possessed by any permanent magnet; and this fact was taken advantage of by Wilde, who constructed what was really a double machine, consisting of a smaller one with steel magnets and a Siemens armature, the current from which was passed through the large electro-magnets of the other, thus exciting a magnetic field of much greater intensity than was before possible. In this field another armature revolved, and furnished the current utilized in the external circuit.

This was hardly accomplished when a most interesting discovery was made, almost simultaneously, by Wheatstone and Siemens, which enabled them to dispense with the permanent magnets entirely. It consisted in utilizing the minute traces of magnetism which exist in all iron, for the production of feeble currents, which, in their turn, excite a more intense magnetization, and in this way the cores of the magnets are quickly charged to saturation. The first machine involving this principle was exhibited by Wheatstone to the Royal Society, on February 14, 1867, and it is not necessary to say that it excited the greatest interest. By a remarkable coincidence, such as occurs now and then in the development of a scientific principle, on the same day a paper was presented to the society by Siemens in which the same improvement in construction was described. The coils about the electro-magnet are either a part of, or a "shunt" from, the main circuit. When the armature is started, either the whole or a part of the current circulates about the field-magnets; and, although it may be feeble at first, by its effect in increasing the magnetism of the cores, it very soon reaches its maximum. The discovery of this method of developing and maintaining the "field" must always be regarded as of the highest importance.

The production of dynamo-electric machinery received a fresh impetus from the construction of a novel machine by Gramme of Paris, in 1870; from which time, in fact, it passes from the experimental to the industrial and commercial stage. Gramme's generator produced practically continuous currents of constant strength, and its merits were due to the introduction of a new form of armature. In the form and construction of this armature, however, Gramme was anticipated by Pacinotti, an Italian, who had constructed a machine on this principle in 1860, but it had remained undeveloped. This armature is the basis of those used in several modern dynamos. Its operation will be better understood after a little further consideration of the conditions under which induction takes place, as discovered by Faraday.

Reference has already been made to the fact, that, in defining these conditions, Faraday made use of the expression "lines of force;" and the study of electro-dynamic induction is greatly facilitated by an understanding of this far-reaching conception. Every one is familiar with the experiment of sprinkling iron filings upon a sheet of paper, card-board, or glass underneath which a magnet has been placed. The arrangement of these filings, especially when the card-board is lightly tapped to facilitate their movement into lines and curves about the



Curves formed by iron filings in the field of a bar magnet.

poles of the magnet, is a very striking and instructive phenomenon. In the first of his "Experimental Researches," Faraday speaks of moving a wire so as to "cut" the magnetic curves, and explains in a foot-note as follows: —

> By magnetic curves, I mean the lines of magnetic forces, however modified by the juxtaposition of poles, which would be depicted by iron filings, or those to which a very small magnetic needle would form a tangent.

From that time these hypothetical lines have been usefully employed in the development of the principles of electro-dynamics. According to this theory, every region in which a magnet would be in any way acted upon or influenced is to be considered as a field of magnetic force. The region immediately surrounding the earth is such a field, as is shown by the tendency of a magnetic needle to rest in a certain direction. All fields of force are pervaded by lines of force, which are lines along which the force acts, and are defined as above. If a very small magnetic needle, suspended so as to be free to move in all directions, be brought into the field of force surrounding a magnet, it will come to rest in, or, more accurately, tangent to, a line of force. If it be moved somewhat from its first position, its direction will, in general, change, showing that the lines of force are not parallel. Such a needle may be used for exploring a field of force; and when the lines are traced out, it will be found, as shown in the experiment with the iron filings, that the lines of force apparently spring out of the poles of the magnet, or, as is often convenient, they may be imagined to come out of the north pole, and to reunite on entering the south pole. They will be found to be most numerous in the immediate vicinity of the poles; so that they may conveniently represent the two essential elements of a force, direction and intensity, the latter being measured by the number of lines cutting through a given area, as a square centimetre, taken at right angles to their direction.

Experiment with the iron filings, or with the small exploring needle, shows that the positio of the poles of a magnet in relation to eac other determines the form, and to some exten the number of lines of force at a given point and the introduction of a third pole in th immediate neighborhood will be found to modify them materially. If two magnets have th opposite poles placed near to each other, or i a magnet be bent so as to bring its poles nea together, it will be found that, in the regio directly between them, the lines of force ar very numerous and nearly straight.

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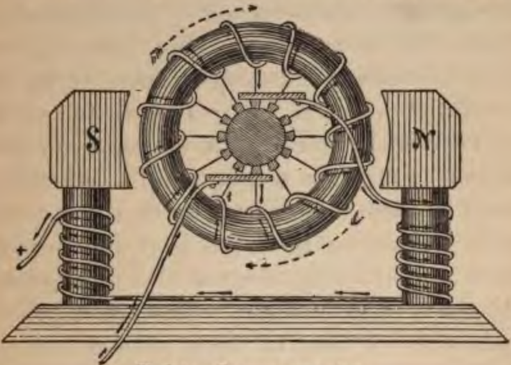
Any operation, therefore, which changes the number of lines of force passing through a circuit, will induce a current in that circuit; and, since this is equivalent to a modification of the nature of the field (as defined by direction and intensity), it may be said that, in general, any modification of the magnetic field in the vicinity of a conductor gives rise to an induced current. A thorough understanding and appreciation of this statement will greatly facilitate the study of induction machinery.

The core of what is known as the "Gramme Ring Armature" consists of a soft iron ring, or often a bundle of soft iron wires bent into a ring and the ends then joined. It is mounted so that it can be rapidly rotated about an axis through the centre of the ring, perpendicular to its plane, precisely as the rim or tire of a carriage-wheel turns about its axis. Around this ring, coils of wire are wound so that their planes pass through its centre; that is, they are situated exactly as if they had been originally wound in a helix around a straight cylindrical bar, which was afterwards bent so that its ends joined, thus forming a ring. A number of separate coils are thus wound; but they are joined together by connecting the proximate ends of every pair of adjacent coils to a strip of metal, generally copper, there being as many strips as there are separate coils of wire. These strips are arranged in the form of a cylinder around the axis of the armature, to which they are parallel; but they are insulated from it and from each other. At the opposite extremities of a diameter of this cylinder the collecting brushes are placed, consisting generally of thin pieces of copper, which are pressed against the cylinder by means of springs or other devices



Skeleton Gramme armature.

which afford some elasticity. The cylinder of bars, with the collecting brushes, constitutes the commutator.

The magnetic field in which this armature revolves is produced by a powerful electromagnet, generally excited by the current which the machine itself produces, the opposite poles of which lie at the extremity of a diameter of the armature. The operation of the machine is not difficult to understand. The soft iron ring core of the armature is constantly rendered powerfully magnetic at two opposite points, very near to the poles of the stationary or field magnet. At points a quarter of a circumference from these it is neutral, so that the action is nearly the same as if the coils were rapidly moved around a ring magnet whose poles were at the ends of a diameter. The result is, that the number of lines of force passing through any particular coil is continually and rapidly increasing and decreasing, and the induced currents are correspondingly strong. These currents are carried to the external circuit through the commutator bars and collecting brushes, and the coils are so numerous that the current is practically continuous.

Since the construction of the Gramme machine, improvement in dynamo-electric generators has been extremely rapid, and their practical use has correspondingly extended. Innumerable patents have been issued for machines involving improvements upon, or modifications of, the Gramme armature. Other forms have been highly developed, and some entirely novel systems have appeared, to compete for popular favor. Among those commonly in use in this country, one of the earliest to achieve success was that of Mr. Charles Brush of Cleveland, O. The Brush armature is similar in many respects to the Gramme, involving, however, important modifications in the form of the iron ring core, and an ingenious arrangement for connecting the coils, which is unlike that adopted in the Gramme armature. The disposition of the field-magnets is also different from that of Gramme. Another well-known machine is that invented by Mr. Weston. This involves several novelties, especially in the construction of the armature. While this resembles the Siemens armature in general form, in detail it differs from it very much. The commutator of this machine is also different from that already described, in that the metal strips are laid on spirally around the cylinder. The object of this is to secure contact of the brushes with two of the strips at all times, so that the current may be more nearly uniform. The Thomson Houston dynamo, which is largely in use for arc lighting, is unique in the form of its armature, which is nearly spherical, and consists of three coils. Mr. Edison, although entering this particular field of invention more recently than many others, has produced a machine original in many respects, and especially remarkable for the tremendous size and power of some individual specimens that have been built.

Many other machines whose success has been practically demonstrated might be mentioned. Each machine doubtless possesses some points of superiority over all the others. In fact, the business of building dynamo-electric machinery has come to resemble very much that of manufacturing steam-engines. Hardly more than ten years ago, the phrases "Gramme machine" and "dynamo-electric machine" were almost synonymous. To-day there is no one machine — there are many; and in making a selection the ruling questions relate to expense of construction, adaptability to special uses, dimensions, weight, etc., precisely as with the steam-engine.

Reviewing briefly what has been said concerning it, a dynamo-machine is seen to consist of two principal parts. One of these is at rest, a huge electro-magnet of some form or other, which, when excited by the current through its coils, creates a magnetic field of intense power.

Within this field is the armature, — a coil or collection of coils, and often with magnetic cores, — which is whirled around its axis at a speed varying from 350 revolutions per minute in Edison's giants to 3,000 or 4,000 per minute in small laboratory machines. The field of force in which it rotates is thick with imaginary lines of force, through which the swift-moving coils plunge, and in virtue of which one may conceive the induction to be brought about. But though the "lines" are imaginary, and the coils touch nothing as they revolve, it must not be forgotten that they meet with great resistance; unless, indeed, no current is being induced. It cannot be too often repeated that the energy of the current which comes out of a machine is never more, and in fact is always slightly less, than the energy put into it. It must be said, to the credit of those who have contributed to the perfection of the dynamo, that already it is able, in some instances at least, to return, in the form of energy of the electric current, more than ninety per cent. of that which it draws from the steam-engine or other motive power. That this remarkable result has been reached in so short a time is unquestionably due to the fact that the *science* of electro-dynamics was greatly in advance of the *art;* so that the latter, by taking advantage of the former, could accomplish as much in a few brief years as has been done in other directions through generations of vague and unsatisfactory empiricism.

It is certainly not one of the least of the achievements of the present age, that out of the small copper wheel and steel magnet of Faraday, producing currents which required for their detection the most delicate and sensitive devices at his command, there has been evolved the gigantic dynamo-machine, requiring an engine of hundreds of horse-power to put it in motion, and producing a current of electricity which requires, for its safe and economical transmission, conductors nearly as large as a man's wrist.

CHAPTER VII.

THE ELECTRIC LIGHT.

THE well-established relation between supply and demand would alone establish the fact that the invention and development of electric generators was the result of a wide-spread recognition of their prospective utility. In a general way, electricity is useful to man as a convenient means of transmitting energy from one point to another. In the early stages of its application, the quantity which could be easily produced was small; but it possessed the valuable qualification of being easily transmitted to considerable distances. It was therefore utilized in operations in which only a very small amount of work was required to be done at the distant point, — only enough to produce a visible or audible signal; and out of its adaptability to this end grew the telegraph.

One of the forms under which it could be made to appear, or into which it could be transmuted, was the energy of chemical action; and it was at an early period made use of in electrolysis, electroplating, etc. That it could also be transformed into heat, and, through heat, into light, was quickly recognized, and the first attempts to utilize it in this way have already been described. The amount of energy required, however, in operations of this kind, is so considerable, that the voltaic battery, when built upon a scale necessary to the production of sufficiently powerful currents, was soon found to be unreliable and unsatisfactory, besides being extremely costly.

The complete solution of the problem was therefore necessarily deferred, until the development of the dynamo-electric machine gave promise that the economical production of powerful currents of electricity was something to be certainly anticipated. Along with this development, and, indeed, sometimes in advance of it, was the working-up of the other part of the problem; that is, the determination of the best means of utilizing these currents in the production of light. This part of the system is generally called the "lamp," the use of the term arising out of an analogy which is obvious.

Although of almost infinite variety, electric lamps are easily classified under two species; in a few rare cases, however, the separation is not quite perfect. The most extensively used is the well-known arc lamp. Of this, the number of varieties is so great that it will only be possible to consider general features, many of which are common to all.

The electric light, as exhibited by Davy and the early experimenters, was the arc light, although nothing deserving the name of lamp then existed. Two pieces of carbon in contact formed a part of the circuit; and when they were slightly separated, if the current was sufficiently powerful, a brilliant light was produced, often taking the form of an arc between the two carbon poles. These poles were consumed rapidly, and the light was suddenly extinguished by the interruption of the current. To provide against this, it was necessary to contrive some device by means of which the carbons could be made to approach each other as they were gradually consumed. Foucault was probably the first to undertake this, and in 1844 he produced a sort of hand-regulator; and at the same time he diminished the necessity for the movement by introducing the use of hard coke, such as is taken from gas-retorts, instead of ordinary charcoal. This was only a few years after the invention of the Grove and Bunsen batteries, by means of which fairly powerful currents could be generated and maintained for some hours. The performance of these batteries gave rise to the hope that the electric light might be economically employed, provided a suitable lamp could be devised; and numerous inventors attacked the problem from this time on. It was soon recognized that a successful lamp must be automatic; that is, it must be capable of adjusting itself, and the control of the force accomplishing this adjustment, if not the force itself, must originate in the variations of the strength of the current.

A brief consideration of the principles involved in the production of heat in any part of a conductor conveying a current will be of use at this point. Reference has already been made to the fact that a current, in passing through a short piece of fine wire, will, if the strength of the current be sufficient, raise it to a red heat, or to incandescence, or will fuse it. It has been clearly proved, that, if the same current be passed through two wires, the heat generated in each will be proportional to the resistance which it offers: hence an iron wire becomes hot or fuses where a silver or copper wire of the same dimensions will be scarcely warmed, because the latter offers much less resistance than the former. Again: it will be remembered, that, all other things being equal, the greater the resistance in a circuit, the less the strength of the current will be. The relation is accurately and beautifully expressed in the law first announced in 1827 by G. S. Ohm. Guided by Fourier's classic investigation of the flow of heat in conductors, Ohm, from purely theoretical considerations, arrived at the conclusion that in any circuit the strength of the current was directly proportional to the electromotive force in the circuit, and inversely proportional to its resistance. In 1841, Joule, in a magnificent experimental research, proved that the heat generated in any part of a circuit was proportional to the square of the current strength, and also to the resistance of that part.

A consideration of these well-established principles will at once show that, in the production of light (heat) at any point of a circuit, it will be desirable to lead the current to that point through conductors offering as little resistance as possible, so that useless generation of heat shall not take place; and to make the resistance at that point just sufficient to produce the required result. Carbon does not rank high as a conductor, and may be made to offer the necessary resistance in a convenient form, and, besides, it does not fuse when brought to a high temperature. In an arc lamp, if the two carbons be in contact and a current is passed, they will not, in general, become greatly heated. On account of more or less imperfect contact where the two rods touch, considerable resistance is there offered, and they may be heated to redness. But if they be now separated slightly, the "arc" will be established. As they are withdrawn from each other, the surface of mutual contact diminishes with great rapidity, and the resistance increases enormously; so that at once the heat generated becomes very great, the tips of the rods are heated to incandescence, and even, when complete separation takes place, the circuit is still completed through the arc of minute particles which are driven off from the poles, and also by the intensely heated air, which becomes a good conductor when raised to a high temperature. The arc continues, until, by the disintegration of the carbons, the interval between them increases, and the resistance becomes so great that the current can no longer be made to bridge over the interval. It is therefore necessary to make them approach each other, but not so far as to reduce the resistance below a certain limit.

The principles involved in the construction of a regulator lamp will now be readily understood. It is only necessary to take advantage of this variation of the current strength, by causing it to bring into play forces which tend to move the carbons to their proper position, and thus to maintain a nearly steady current through the lamp.

As already stated, innumerable methods have been devised for doing this. Almost every form of dynamo machine has its accompanying lamp, so as to constitute a complete system. In some of the earlier forms, as in Foucault's first automatic regulator, a train of clock-work was used for producing motion in the carbons, the train or trains (for sometimes one is used to bring together, and another to separate the carbons) being started by the increase or decrease of the current strength beyond certain limits. This may be accomplished by causing the current, or a part of it, to pass through the coils of an electro-magnet. When the current weakens, the magnet releases its armature, and this action starts the mechanism, which causes the carbons to approach each other: when it becomes stronger, the armature is attracted, and this arrests the motion of the mechanism, and stops the approach of the poles.

There are many more successful regulators than Foucault's; and in most of them the action of the current itself, aided by gravity, is sufficient. In many forms two electro-magnets are used, one of which is in circuit with the carbons, while the other, of much higher resistance than the arc, and therefore taking only a small part of the current, is connected *around* the carbons, as a shunt; so that the current divides, the greater part passing through the carbons and one magnet, and the smaller part through the other magnet. These magnets are so arranged as to oppose each other in their tendency to change the position of the carbon rods. If the latter are too near together, the resistance of the arc is relatively small, and a larger proportion of the current will go through the coil of the magnet in circuit with the carbons. The action of this magnet is to separate the carbons; but, as this separation continues, the increasing resistance of the arc throws more and more of the current into the coil of the other magnet, which shortly becomes the most effective, the movement is arrested, and, if necessary, the carbons are made to approach each other again. It will be observed that this method of connecting and using two magnets possesses the great advantage of making the adjustment dependent upon variations in resistance *within the lamp itself*, — a condition essential to the successful use of several lamps on the same circuit. Nearly all lamps in practical use have only one movable carbon. This is the upper one, and its descent is generally caused by its own weight, the mechanism operating to check its downward movement, and also to lift it through small distances. A device is also attached, in virtue of which the breakage of the carbons, or their exhaustion, is not allowed to interfere with the flow of the current through the lamp, — an arrangement necessary to prevent the failure of one lamp resulting in the stoppage of all others on the circuit. It may be easily attached to the high resistance magnet above described; so that when, through accident to the carbons, the current through its coils becomes excessive, an armature is drawn up which permanently shifts the main current through the lamp by an independent route.

Mention ought to be made of a novel form of arc light which, a few years ago, attracted much attention. It is known as the "Jablochkoff candle," and consists of two straight pieces of carbon placed parallel to each other, separated by a thin layer of some insulating material. The arc is formed from one carbon to the other across the end of this insulating layer, which is consumed or volatilized as the carbons grow shorter. Thus all mechanism is dispensed with, the carbon rods being at the proper distance throughout their length. This system has not proved as successful as it promised to be in the beginning.

The performance of the arc lamp is being constantly improved: it is extensively in use all over the world, and is an established commercial success. Its light is extremely brilliant, but, even with the best regulators, still somewhat irregular: it therefore finds its place as an illuminator of streets, large public halls, manufacturing establishments, etc., and it cannot yet be said to be suitable for what may be called "domestic" use.

Nothing is more natural than that the appearance of a platinum wire, heated to a white heat by the passage of a current, should suggest the possibility of a system of electric lighting by incandescence. But, probably owing to the fact that most metals melt before reaching a temperature at which the percentage of luminous radiation is large, and also, doubtless, to the greater brilliancy and novelty of the arc light, progress in this direction was for a time somewhat slow. The first serious attempt to construct an incandescence lamp appears to have been made about the year 1845, by J. W. Starr of Cincinnati, O. Mr. Starr carried his invention to Europe, hoping to receive recognition there. After meeting with some encouragement and securing some assistance, he started to return home; but, unfortunately, he died at sea, at the age of twenty-five years. He seems to have anticipated many of the recent investigations in this direction, and his scheme included the production of the necessary electric currents by improvements in induction machines. His lamp consisted of a piece of carbon, heated to incandescence, in a Torricellian Vacuum. He was followed by numerous inventors, who experimented with different substances, as Starr had done before them, but who finally settled upon carbon as the most suitable. At present there are a number of well-known incandescence lamps, differing from each other rather in details of construction, and in the manner of preparing the carbon, than in any essential particular.

The first real impetus in this direction was given by the experiments of Mr. Edison. With characteristic industry and enthusiasm, when he first attacked the problem, now nearly ten years ago, he made an exhaustive examination of the adaptability of various materials, during the course of which he discovered several interesting and before unrecognized properties of metals. But the results of his investigations led him to adopt a carbon filament, and a particular form of it, which he prepares from a fine quality of bamboo. Strips of this are cut to the proper size and form, and are then "carbonized" by being exposed to intense heat while confined between two plates of iron or nickel. After this process, the extremities of the filaments are electroplated with copper, so that a proper junction may be formed with the platinum wires by means of which they are sealed in the well-known pear-shaped glass chamber. These chambers are exhausted by the use of mercury pumps, and the necessary attachments for connecting the lamps in the circuit are added.

Another form largely in use is the Maxim lamp, the filament of which is cut out of cardboard by means of a die of the proper form, and afterward carbonized. The Swan incandescence lamp is extensively used in this country in connection with the Brush system of electric lighting. Its filament is of cotton thread, which receives a preliminary "parchmentizing" by being immersed in a solution of sulphuric acid and water, after which it is carbonized.

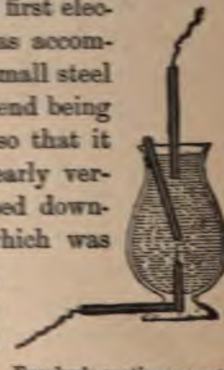
Several other forms of incandescence lamps are candidates for public favor, and generally they do not differ in any essential feature from those described. At first the most serious difficulty with lamps of this species was their tendency to break down through the disintegration and volatilization of the carbon filaments, after long exposure to the high temperatures demanded. This has been largely overcome, and there is little trouble to-day in obtaining lamps of long life.

The incandescence system offers many advantages over arc lighting, the most notable being the ease of distribution of the light, and its almost absolute steadiness. The most perfect arrangements for its introduction and use have been devised, and its superiority over gas or other illuminants is admitted by all. Indeed, to one familiar with the present condition of the art, the surprise is not that the incandescence lamp can be used, but that it is not used much more extensively than it is. If the people were a little less conservative in the matter, and electric lighting companies less anxious to secure extravagant dividends upon their stock, electricity would shortly take the place to which it is justly entitled, as the most perfect illuminant at present known.

CHAPTER VIII.

THE TRANSMISSION OF ENERGY BY MEANS OF ELECTRICITY. — THE ELECTRIC MOTOR.

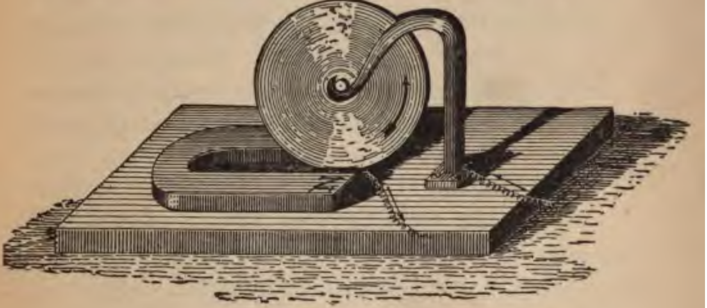
IN 1821, Faraday, then an assistant to Sir Humphry Davy in the Royal Institution, succeeded in producing continuous rotation of a magnet around a wire through which a current was passing. This first electro-magnetic rotation was accomplished by immersing a small steel magnet in mercury, one end being weighted with platinum so that it floated in a position nearly vertical; a current was passed downward through a wire which was plunged in the mercury, and about this wire the magnet revolved as long as the current flowed.



Faraday's continuous rotation of a magnet about a current.

By a reversal of this, that is, by using a fixed magnet and a movable conductor, Barlow devised what is known generally as "Barlow's Wheel," the form of which is almost identical with that of Faraday's first dynamo, already described.

Instead of turning this wheel, and thus generating a current of electricity, a current is led into it from any convenient source, entering at the axis, and leaving at the circumference, or *vice versa.* If the wheel or disk be properly placed between the poles of a magnet, as in Faraday's experiment, rotation will be set up, the direction of which will depend upon the direction of the current and the position of the magnetic poles. The current which causes motion in this simple machine may come from another precisely like it, except that in it the disk must be turned by hand or by some other source of mechanical energy. The experiment



Barlow's Wheel.

is useful as showing the interchangeability of the dynamo, which generates a current of electricity, and the *motor*, which converts that current back into what is generally known as "mechanical energy," the motion of visible masses of matter.

Nearly all forms of telegraph receiving instruments are machines in which this conversion is made; but in few, if any, of them is continuous rotation produced. As this is almost necessary in any machine constructed for the general purpose of "doing work," the name "electromotor" is usually understood to belong only to such arrangements as produce rotation. Numerous ingenious and costly experiments were made in the early days of applied electricity, following Faraday's discovery of electro-magnetic rotations. In a certain sense, they were all failures, although they were not without their value to the inventor and the student of electricity. In the first place, the methods then utilized for generating powerful currents of electricity were expensive and troublesome; and, in the second place, ignorance of the real principles involved led to a faulty construction of the motors used.

In spite of this, machines capable of doing considerable work were built. In this country Henry and Page did something to further the solution of the problem, the latter, especially, devoting much time and labor to it. After much experiment, he built a motor which did work equivalent to five or six horse power, and with which he ran a circular saw and a lathe. He also applied it with considerable success to the movement of cars on railway tracks. In Europe, Davidson, Froment, and Jacobi worked upon motors, and the last constructed one which attracted much attention at the time, and was possessed of much real merit. It was large enough to drive a boat carrying a dozen people. A large battery of more than one hundred cells was required to run the machine, and the power produced was exceedingly expensive.

All of these machines are now interesting from an historical stand-point; but, for reasons already given, they were not successful. The improvement of the dynamo-electric machine, and the recognition of its "reversibility" (by which is meant that a dynamo will run as a motor if a current is supplied), revived interest in the subject, and within the past few years many valuable and important advances have been made. Although the construction of motors cannot yet be said to have passed the experimental stage, there are many purposes for which they are especially adapted, and for which they are destined soon to come into general use. When water-power may be obtained at little cost, a current of electricity may be generated, and conveyed to a neighboring point, and there utilized for running light machinery so as to be really more economical than a steam-engine. Electricity is not likely to be called in, except where power is to be transmitted some distance; and it must be remembered, that, even when the dynamo and motor are constructed on principles theoretically perfect, the latter must always give up somewhat less energy than it consumes, so that, in the present state of the art, not a very high percentage of efficiency is to be expected. Considered as a question of cost per horse-power, the movement of the armature of a relay in a telegraph-office is enormously expensive; but questions of convenience and availability often override that of cost. The ease with which the electric motor can be manipulated and controlled, the freedom from danger by fire, and the fact that it can readily be introduced wherever a current from a dynamo is at hand, are strong arguments in its favor, and give it an *availability* far beyond that of the steam-engine.

Extensive experiments have been made in this country and in Europe in utilizing the motor for driving street-cars and cars upon short railway lines, and with results that give promise of ultimate success. Several short electric-railway lines are in operation in Europe, and one or two lines for street travel in this country. In short, the motor is now in a stage of its development somewhat similar to that of the electric light ten years ago, and there is reason to believe that it will yet overtake its more brilliant forerunner.

CHAPTER IX.

THE TELEPHONE.

THE name of Dr. Charles Page has already occurred several times in these pages. It was his fortune to be a pioneer in several of the most important developments of electricity; but none of his discoveries were more novel, or led to more important and interesting results, than a curious observation which he made in 1837. It was that a bar of iron could be made to emit sounds when rapidly magnetized and demagnetized, and that the pitch of the sound depended on the rapidity with which the changes were made. This was the first recognition of the possibility of producing musical tones by electricity.

Thirty-nine years later there was exhibited, in the Centennial Exhibition at Philadelphia, a small instrument, which the most distinguished electrician of the time pronounced to be the "wonder of wonders in electric telegraphy." By its use, not only was sound produced by means of electricity, but a sound at one end of an electric circuit was reproduced at the other, and with such fidelity that human speech at one end was faithfully repeated at the other in every respect but in loudness. The instrument was exhibited by Alexander Graham Bell, who had patented the invention only a few months before. As exhibited at Philadelphia, it was far from being satisfactory in its operation, but it proved that the problem of "talking by telegraph" had been solved.

The transmission[1] of musical tones by means of electricity had been previously accomplished, and was an operation well understood. Philip Reiss, in Germany, had, many years before, made use of Page's device as a receiver, and had contrived a transmitter very similar in appearance to several in use to-day. Other methods of accomplishing the same result had been contrived, and doubtless more than one inventor had the transmission of articulate speech in mind. Indeed, another American, Mr. Elisha Gray, was at work in this direction; and, by a curious coincidence, Mr. Gray deposited his specifications and drawings for a *speaking telephone* in the United States Patent Office, in the form of a caveat, on the 14th of February, 1876; and on the same day Mr. Bell filed his application for a patent, the latter being received a few hours earlier than the former. The coincidence becomes more interesting when it is remembered that it was also on the 14th of February (1867) that Wheatstone and Siemens simultaneously presented to the Royal Society their independent discovery of the important fact that dynamo-electric machines could be constructed and operated without the use of permanent magnets. It would seem desirable for discoverers and inventors who have anything of importance to communicate to the public on this particular day of the year, to lose no time in its announcement.

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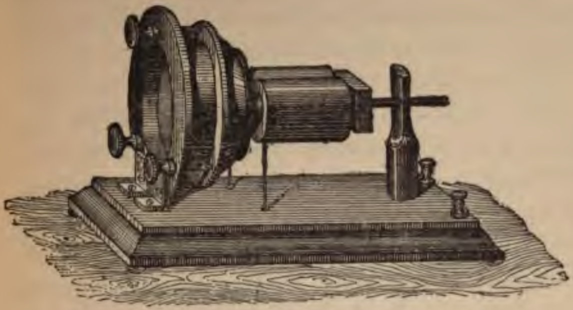
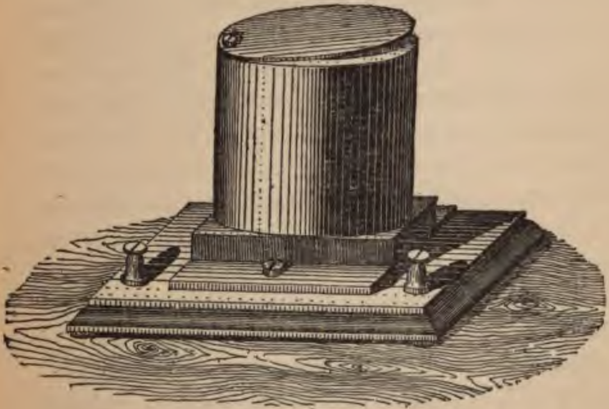
[1] The word "transmission" is here and afterward used to avoid circumlocution. In reality, sounds are not transmitted by the electric telephone, but simply reproduced at the other end of the line.

Since the successful introduction of the telephone, innumerable claimants for priority in its invention have appeared. It is claimed that Reiss transmitted speech with his device, and other inventors claim to have succeeded in accomplishing the same thing previous to the date of Bell's patent. The question has long been in litigation, and it will perhaps sometime be settled by the highest judicial tribunal. It cannot be denied, however, that Bell's invention was the immediate cause of the development of speech transmission by means of electricity.

The Bell telephone, as originally produced, was an extremely interesting combination of a dynamo-electric machine and a motor, the two



Bell's transmitter as exhibited in Philadelphia in 1876.

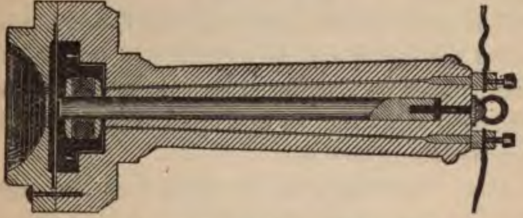


Bell's receiver as exhibited in Philadelphia in 1876.

being identical in form and construction; and, as such, its operation will be readily understood. When a sound is produced, energy is expended in its production: this energy cannot be destroyed, although it can seldom be recovered. Ordinarily, when a word is spoken, the energy necessary to or consumed in its utterance first appears as a series of waves of compression and rarefaction in the air, where most of it is finally transformed into heat. It is possible, however, to transmute at least a part of this energy into other forms. Solid bodies may be made to vibrate by the sound of the human voice, and by a suitable contrivance it may be made to do work in running a machine and overcoming other resistances, always, of course, of no great magnitude. In the telephone the sound of the voice is made to do work; this is converted into the energy of an electric current; and this, in turn, is reconverted into mechanical energy, resulting in sound. The form of the ordinary Bell telephone receiver is so well known as hardly to require description.

Internally it consists of a small cylinder of steel which is permanently magnetized, and around one end of which is a coil of fine wire. Just in front of this end of the magnet, but not quite in contact with it, is a thin circular membrane or disk of iron supported at its circumference. Originally the transmitter was precisely like this receiver. One end of the fine wire coil of each is joined to the line connecting the two points, and the other end is connected with the earth.

Now, if a sound be produced near the thin disk of the transmitting instrument, it will be made to vibrate. Although these vibrations are exceedingly minute, they are sufficient to produce changes in the magnetic field in which the coil of fine wire lies, as in Page's induction machine; and, as explained in a previous chapter, any change in the nature of this field will produce induced currents in the wire coil. These currents will be transmitted through the line, and, flowing through the coil surrounding the pole of the receiving magnet, will produce variations in the intensity of its magnetization. Just what goes on at the receiving end has been a subject of considerable dispute, and the opera-



Sectional view of Bell's receiver as now generally used.

tion there is unquestionably a complex one. Since sound is produced, there must be vibrations of parts of the receiver; and these must vary in rapidity and form, along with the variations in rapidity and form of the electric waves generated by the action of the transmitting instrument. There is doubtless a vibration of the thin plate of the receiver, due to variations in the strength of the pole of the magnet near which it is placed; but talking can be heard when the metal disk is absent, so a part of the result must be attributed to what is called "molecular" vibration, as in Page's original device for producing sound.

But the wonder of it all is, that the transmitting disk takes on, and the receiving apparatus reproduces, all the various phases and forms of motion impressed upon the air by the voice, and essential to reproduction of that voice in articulate speech. Nothing like it in simplicity of construction, combined with complexity of operation, is to be found in any other human contrivance.

The electric currents thus generated and transmitted are necessarily extremely minute. The amplitude of vibration of the disk has been estimated to be only a small fraction of the length of a wave of yellow light, of which there are about forty thousand to the inch. It has also been determined that the receiver reproduces not more than one ten-thousandth part of the "volume of sound" received by the transmitter. As a "motor," it must be considered as having extremely low efficiency, although, on the whole, very effective.

The telephone as at first used, and as just described, was much less satisfactory in its performance than it is at present. Its working has been vastly improved by the use of other forms of transmitting instruments, by means of which variations of current strength of much greater intensity are transmitted over the line, while still retaining the characteristics necessary for the reproduction of speech.

The transmitters generally in use at present depend upon a curious and important discovery made by Hughes in 1878. It consisted essentially in the fact, that, if a piece of carbon be allowed to rest lightly upon another, and an electric current be passed from one to the other in a circuit in which there is a Bell telephone receiver, the latter will respond to the faintest sounds in the vicinity of the carbons. Various other substances (imperfect conductors are generally better) may be used instead of carbon, and the arrangement is called a "microphone," Its operation is due to the fact that imperfect contact exists where the two carbons touch each other; and the slightest disturbance is sufficient to alter the extent of that contact, and thus to vary the resistance of the circuit. In accordance with the law of Ohm, the current varies with the resistance; and this variation of the current acts, as already explained, to produce sound from the receiver. Various forms of transmitters employ the principle of Hughes's microphone. An important modification consists in the arrangement of the transmitter in a local circuit rather than in the line. The result of this is that much greater variations of current strength can be produced. The transmitter includes a much larger part of the resistance of the local circuit than it would of that of the line; so that, for a given alteration of its own resistance, that of the circuit is altered by a much larger percentage. The local circuit includes the primary wire of a small induction coil, the secondary or outer coil of which is connected to the receiving instrument through the line. The operation of the system is somewhat as follows: the sound-waves falling on a membrane or disk similar to that in the receiving instrument, sets it in motion in such a way as to produce variation of pressure at the microphone contact, generally placed in the rear of the disk, and corresponding variations in the strength of the local current result. Changes in the strength of a current flowing in the vicinity of a coil are equivalent to movements of that current towards or away from the coil; and, as shown by Faraday, induced currents must traverse the coil. These induced currents go into the line, and do their work in the receiver at the distant end, precisely as in the original form of the instrument. The introduction of the microphone transmitter with the local circuit and induction coil has greatly strengthened the telephone, and rendered its use much more easy.

Mr. Edison devised a transmitter in which a small disk or button of soft carbon, prepared from lampblack is used as the element of variable resistance, the movements of the membrane modifying the pressure which it normally exerts upon the carbon. Owing to the excessive sensitiveness of the resistance of this form of carbon to variations of pressure, it is admirably adapted to this use. A large number of transmitting instruments have been invented; but not many have come into use, except those which depend for their operation upon the principle of the microphone. A few devices for telephone receivers other than Bell's have been invented, one or two of which are novel and original, especially those of Edison and Dolbear. The latter may be called an "electro-static" telephone, as it contains no permanent magnet and no helix of wire. In fact, it depends upon the principle of attraction and repulsion between two electrified bodies. Practically, it is an extremely satisfactory receiver. Difficulties of a legal character have prevented the introduction of these instruments up to the present time.

CHAPTER X.

SECONDARY AND THERMO-ELECTRIC BATTERIES.

ONLY a few years ago a good deal of commotion was created, in both the scientific and the unscientific world, by the appearance of what has been variously called the "storage battery," the "secondary battery," and the "electric accumulator." Some method of economically storing or accumulating energy so as to be easily transportable has long been the hope and aspiration of every intelligent mechanical engineer. For a time the belief that the problem was solved through the use of electricity was wide spread; and innumerable stock companies, representing a fabulous amount of capital, were quickly organized for the purpose of developing this new industry.

The expectations of the promoters of these schemes have not been realized, but a good deal of valuable information concerning the behavior of secondary batteries has been accumulated; at an expense far greater, however, than would have been necessary, had the whole subject received in the beginning an exhaustive examination at the hands of a competent commission under government authority and at government expense. The vast importance of the questions involved would seem to justify such a course.

The first secondary or storage battery ever made has already been referred to. It was constructed by Ritter in 1802, and its operation has already been explained. The subject was revived in 1843 by Grove, who constructed a gas-battery to illustrate the operation of polarization; and again by Gaston Planté in 1859, who went to work systematically to see what could be done in the way of storing electricity. He discovered, after trying many metals, that electrodes of lead, immersed in dilute sulphuric acid, were more suitable than anything else for the production of polarization effects. After passing a current for some hours, from a couple of cells of Bunsen's battery through a cell composed of two large sheets of lead immersed in this liquid, he was able to take from it currents of great strength and considerable duration; in other words, large quantities of electricity could be received back from the cell. His large cells were [illegible] by placing [illegible] sheets of lead [illegible] by the [illegible] [illegible] which of [illegible] into a compact cylinder. This, when immersed in a vessel of dilute acid, could be charged by means of a current from a dynamo or from an ordinary battery. The action which took place during the charging was at first simply the liberation of the gases oxygen and hydrogen, as in Ritter's battery; but these gases combined with the lead, altering its appearance, causing it to have a spongy texture, and covering one of the electrodes with a film of peroxide of lead. It was found that if the charging was repeated first in one direction and then in the other, for some days, a great improvement in the character of the cell was brought about, and this operation was called "forming" the cell.

Planté's work did not command great attention — not, indeed, as much as it deserved; and it was a modification of his method devised by Faure which created the first excitement in financial circles. Faure's improvement consisted in coating the lead plates in the beginning with red lead, by which means the operation of forming was avoided, and the capacity of the cells was greatly increased. The introduction of Faure's battery was quickly followed by a great number of proposed secondary or storage batteries, in all or nearly all of which electrodes consisting of lead plates are made use of. They are ther[illegible]mely heavy, and are difficult to transport. As a means of conveying energy from one point to another, they present only advantages of availability. Four cells brought to London in 1881 weighed seventy-five pounds, and were said to be charged with one million foot-pounds of energy, equal to the work of a horse for half an hour; but this is not more than the energy stored in an ounce or two of coal. The energy of the battery is, however, much more easily drawn upon and utilized than that of the coal.

It must not be imagined that electricity is actually stored up in one of the cells; what is stored is the energy of the electric current, which disappears in producing certain chemical changes in the cells, a large part of this energy being capable of reproduction as an electric current. A form of battery proposed by Messrs. Thomson & Houston illustrates the principles of their operation. The ordinary gravity-battery contains, as is well known, a plate of copper at the bottom of the cell, and over this is a solution of sulphate of copper which is blue in color. Above this is a clear solution of sulphate of zinc, in which the zinc electrode rests. If the zinc and copper poles be joined by a short, thick wire, a current of electricity passes, metallic copper is deposited the copper plate, and zinc is dissolved in the solution. If this operation be allowed to continue, and no fresh crystals of sulphate of copper be added, the blue color will finally disappear, the copper having all been deposited in a metallic form. Now pass a current from a dynamo, or from another battery of several cells, in a direction opposite to that of the cell in its original condition, and the "recovery" of the cell will take place; that is to say, zinc will be deposited on the zinc plate and a solution of copper sulphate will be formed. When this is completed, the cell may be used as an independent source of electricity, as before. Messrs. Thomson & Houston do not, of course, make use of the cell in precisely this form, but begin with a solution of zinc sulphate in which is immersed a copper plate and also a carbon plate, the latter taking the place of the zinc electrode in the arrangement described above. When a current from a dynamo is passed into a cell or series of cells of this kind, copper is dissolved from the copper plate, and zinc is deposited on the carbon; so that at the end of the operation the cell is itself capable of generating a current, and in so doing it falls back to its initial condition. The progress of charging can then be repeated.

There are innumerable ways in which storage batteries would be immediately utilized, if they were found to be trustworthy. As an adjunct to electric-lighting plants, they would be especially valuable, as the energy consumed at night could be accumulated during the day. Many earnest attempts to perfect them have been made, and it cannot be denied that they have been afforded a fair trial. Although they are now in use to some extent for special purposes, it must be admitted that much remains to be done in the way of improvement, in order to establish a claim upon the confidence of the public. Their want of durability is their most serious fault. For a time, and in skilled hands, they may behave admirably, but they may unexpectedly break down without apparent reason.

Two principal methods of generating electricity have thus far been considered, — that of the battery, due originally to Volta; and that of the induction machine, due originally to Faraday. No account, however brief, of the growth of the science of electricity, or the development of the art, would be complete without reference to a third method, which was discovered by Seebeck of Berlin in 1821. One of the earliest contributions growing out of Oersted's discovery, it has since played a most important part as affording an instrument of great lue for purposes of research, as well as in raising questions of great theoretical interest and importance. Seebeck's discovery was that if a circuit be formed of two wires of different metals, or even of the same metal in different physical conditions; and, if one of the junctions of these two wires be at a higher temperature than the other, a current of electricity will be established in the circuit. By selecting metals best adapted for the purpose, and by combining them after the manner of a battery arranged in "series," currents of considerable strength may be produced in circuits of low resistance. Combined with a very sensitive galvanometer, a thermopile thus constructed furnishes a method for determining the minutest differences of temperature. Numerous attempts have been made in recent years to construct thermo-electric batteries of such dimensions as to produce currents of electricity comparable with those produced from an ordinary battery or dynamo-electric machine. By using as many as six thousand elements, a current sufficient to maintain an electric light was generated in Paris in 1879.

The efficiency of these batteries is extremely low, not more than four or five per cent. of the heat applied being reproduced in the form of electric energy. In spite of this, they would be widely used were it not for the fact, that, like the storage battery, they are liable to deteriorate. This difficulty does not seem insurmountable, and the thermo-battery may yet be extensively employed in work for which it is especially adapted. By its use, heat is transformed directly into the energy of electric currents, without the interposition of a steam-engine; and in spite of its low efficiency, in connection with a fairly perfect system of electric storage, it may occupy a wide field of usefulness in rescuing vast quantities of waste heat from useless dissipation.

CHAPTER XI.

CONCLUSION.

FROM the rubbing of a bit of amber, to the telegraph, the telephone, the electric light, and the electric railway, is a long distance in more than one sense. That it has been traversed by the ingenuity of man, and mostly during the last hundred years, goes far to justify the most extravagant praise which, even by poetical license, man has bestowed upon himself. The attempt has been made in these pages to give a somewhat connected account of this wonderful progress, and especially to bring into prominence the few principal points from which these successful attacks upon the mysteries of nature have been made. Within this hundred years there have been three notable discoveries in electricity, around which all others cluster, and from which they all have grown. These three have immortalized the names of Galvani and Volta, Oersted and Ampère, and Faraday.

It has been impossible to consider, indeed it would have been impossible in these pages to catalogue, all of the contributions to the science, or the devices of ingenious inventors who have provided for its practical application. It has only been attempted to develop the fundamental principles which underlie these applications, and to illustrate them in the explanation and discussion of some that are distinguished for their importance, or novelty and promise.

It might naturally be expected that something in the way of a forecast of the possible future of this department of human knowledge would be undertaken. However tempting that task might appear, the usefulness of its performance might seriously be questioned. The history of prophecy in the past would seem to prove that it is at least dangerous to predict what can *not* be accomplished in the future. It may be well, however, to put a check upon the extravagance of the imagination in matters of this sort. The enthusiastic should not forget that the greatest generalization of modern science has for its principal object the establishment of limitations. The doctrine of the conservation of energy has done for the philosopher and for intelligent inventors what the doctrine of conservation of matter, as established by the early chemists, did for the seeker after the philosopher's stone. It has shown that no energy can be obtained from a place where it is not, and its recognition guides alike the student of science and the so-called "practical" man in their researches and inventions. More than ever before in the history of science and invention, it is safe now to say what is possible and what is impossible. No one would claim for a moment that during the next five hundred years the accumulated stock of knowledge of geography will increase as it has during the last five hundred. The great continents have been discovered and explored; the great rivers and mountain-ranges have been traced, measured, and mapped; and, although much still remains unknown, future progress must be mostly in matters of detail. In the same way it may safely be affirmed that in electricity the past hundred years is not likely to be duplicated in the next, at least as to great, original, and far-reaching discoveries, or novel and almost revolutionary applications. Nevertheless, in passing over the ground the reader must have observed many avenues opening into the region of the possible which are yet unexplored. Although more than fifty years have elapsed since Faraday's discovery of induction, the full benefits to be derived from its development are not yet realized.

It can be fairly expected that great advances will be made in the near future, and particularly as progress in one department of science is so linked with that in others. While growth may in general be anticipated along the lines already laid out, the discovery of a new element, possessing unusual and remarkable electric properties, or the production of a new alloy with similar characteristics, might at once open the way to a host of practical applications of electricity not now dreamed of. It is also to be expected that many devices at present more or less imperfect and unsatisfactory will be perfected and completed in the not distant future. The telephone and the electric light are the first applications of electricity to claim admission to every home, the special training necessary to the manipulation of the telegraph naturally restricting its use. The telephone, ten years after its first introduction, is more satisfactory in its performance, and far more extensively used, than was the telegraph in the corresponding period of its history.

In every house, in cities and towns, there must be a supply of electricity to be drawn upon, as water is at present. Then, in addition to its use as a source of light, much of the labor of the household will be performed by means of small electric motors. The economical storage of this form of energy must soon be accomplished, and this will greatly enlarge the field of its usefulness. The successful transfer of the energy of falling water, through metallic conductors to distant points, is one of the results which can and will be reached. "Seeing" by electricity has been much talked of: some schemes for its accomplishment have been suggested, and the operation is one which cannot be classed with the impossible. These and many other things will doubtless come in time, along with other useful applications of the electric current not now thought of.

From an origin remote and uncertain, electricity came down to modern times, and for more than two thousand years almost nothing was known of the laws which control it. In 1786 it appeared to Galvani in the guise of a stranger, and as such received a hearty welcome. Its identity was soon established, but it proved to be much more amenable to treatment in the new character than in the old. During the past hundred years it has pushed its way to the front, and made itself indispensable to the comfort and happiness of man, to a degree little less than marvellous. It now enters upon the second centenary of its new life, during which there is every reason to believe that its usefulness will be vastly extended, although its growth and development may be less phenomenal.

POSTSCRIPT, 1890.

BARELY three years have elapsed since this little book made its first appearance. It was designed to be a brief chronicle of the principal events which were strung along the first century of modern electricity, at the end of which discovery and invention were seen to be advancing at a pace apparently justifying the prophecy that the second century might rival the first. Already some notable advances have been made, and although they belong to the century which is to come, rather than that which is completed, it seems not improper to add a few pages descriptive of some of the more important.

No one can have failed to notice the large extensions of the practical applications of electricity, and especially in its production and distribution for purposes of illumination. Electric-lighting plants have multiplied with great rapidity, and in America there is scarcely a town containing more than two or three thousand inhabitants that does not enjoy the blessings of the new illuminant. It has been found to be particularly well adapted to the necessities of smaller cities and towns, the original expense of the equipment for lighting being much less than that required by a gas establishment. The electric light is displacing other methods of illumination on steamships and men-of-war and a fair beginning has been made in its use on railway trains. An advance even more rapid has taken place in its utilization as a means of transmitting mechanical energy, and particularly in the application of electricity to street-car locomotion. The electric car is now to be seen in most large cities, and in many smaller ones, where it is no longer regarded as a novelty. Most, if not quite all, of the difficulties encountered in its application to locomotion have been overcome, and the exploitation of electric railways may now be regarded as a legitimate business.

Great attention has been paid to the development and introduction of alternating currents, and alternating systems have come to the front with great rapidity, claiming, and in many respects justly, decided advantages over those using direct or continuous currents. As this development has taken place largely during the past three or four years, it will be worth while to refer in some detail to the difference between this system and that of the continuous current. In chapter VII. the use of a commutator as a part of a dynamo is described. By it the current is directed into the main circuit from a coil or a part of a coil while it is passing through a particular part of the magnetic field in a particular direction, and thus the current through this circuit, while it may vary in strength from one moment to another, is always going in the same direction; and if the strength variations are small enough, or if they occur with sufficient frequency, the current is practically continuous. If, however, the extremities of an armature coil are permanently connected, through suitable sliding contacts, to the ends of the conductor forming the main circuit, the current will be reversed in this circuit, just as it is reversed in the armature coil as it moves through opposite portions of the magnetic field. As this magnetic field cannot be maintained by these rapidly reversing currents, it will be seen that this system requires that the field magnets must be permanent steel magnets, as was the case in many of the earlier machines, or their coils must receive a continuous current from a separate machine or equivalent device, such as commutating a few of the coils for the production of a continuous current. The armature usually consists of a number of coils surrounding iron cores, which revolve rapidly in front of a corresponding number of fixed electro-magnets, although in some machines the revolving magnets constitute the inducing portion, and the currents are induced in the stationary coils. These currents are reversed with great frequency, often hundreds of times in a second, and are especially suitable for certain operations, such as feeding the Jablochkoff Candle, with which they were at one time quite extensively used. Although they suited other systems of electric lighting, the production of nearly continuous currents through the invention of the Gramme Armature resulted in their being neglected for several years.

Alternate current machines are especially adapted for the production of currents of high electro-motive force and relatively less strength. By reference to the statements of Ohm's law, together with that of Joule, found in chapter VII., it will be seen that the heat produced between two points in a conductor conveying electricity, and therefore the energy expended, is equal to the product of the electro-motive force and the strength of the current. This product may be maintained at a given value through a wide range of either of these factors, provided the other be suitably varied, and it might thus appear that for the transmission of energy it was matter of no moment whether a strong current with low electro-motive force or a weaker current with high electro-motive force was used. It does not follow, however, that the actual economy of the operation will be the same in b cases. In conveying the energy to the po where it is to be utilized, either as light mechanical power, it is necessary to avoid loss the conductors as far as possible. Heavy curren require heavy conductors, and the original co of a plant for their distribution is much greate than in the case of weaker currents, although th energy transmitted may be the same. This gives "high-tension" systems a great advantage in the matter of original investment of capital, provided they are just as efficient in their operation. For the utilization of these high-tension currents it has been found advisable to transform them, at or near the point where they are used, into currents of greater strength and less electro-motive force. The device used for thus changing alternate currents is known as a "transformer," and although of very recent application the principle on which it depends was first recognized and announced by Joseph Henry as long ago as 1838. In his own language, it was that "*a quantity current can be induced from one of intensity;*" that is to say, a weak current with high electro-motive power may by induction give rise to a strong current with lower electro-motive force. In the well-known "Induction Coil," a current of considerable strength is passed through a coil of coarse wire, known as the primary coil, wrapped about a soft-iron core, the whole being surrounded by a long coil of very fine wire called the secondary coil. By rapidly making and breaking the current in the primary, electricity of a sufficiently high "tension" is produced in the secondary to maintain a series of discharges through a considerable air-space.

It is only necessary to reverse this process, with proper modifications to secure efficiency, and the "transformer" is the result. The rapid reversals of current in the long, fine wire induce currents in the heavier conductor, which, although alternating, are of greater strength and lower electro-motive force.

Experiment has shown that the "efficiency" of these transformers is high, not a very great per cent. of the energy being dissipated in the operation. The introduction of transformers has given an impetus to the use of alternating current systems, which are still somewhat handicapped, however, by the generally admitted fact that alternating currents of high tension are more dangerous to life than others.

Prohibitory and restrictive legislation is threatened, but it should not be forgotten that similar objections were urged only a few years ago against electricity of any kind, and a little earlier against the use of gas, steam, etc. It is interesting to note in connection with this, that one of the most recent proposed uses of electricity is as a means of producing death in the legal execution of criminals. The State of New York has, by act of its General Assembly, adopted this as a substitute for hanging; at least one criminal has been sentenced to death by electricity, but on a plea that the law is unconstitutional, the execution has been delayed, and the question is still with the courts.

One of the most interesting and important of the recent applications of alternate currents and transformers is the device for welding by electricity invented and perfected by Professor Elihu Thomson. A "low-tension" current from a suitable transformer is passed through the junction of the metals to be joined, and by reason of the higher resistance at that point, the pieces being held together by a light pressure, heat is generated, the ends in contact are fused and softened, and while in this condition are pressed firmly together by a slight movement of the clamps in which they are held. By this very ingenious process, it is not only possible to weld metals hitherto difficult or impossible to join in that way, such as copper, brass, cast-iron, etc., but actually to weld together dissimilar metals, pieces of different cross section, and to form welded rings of large or small diameter. Pipes may be joined in this manner, and wires, from the smallest up two or three inches in diameter, the operation quiring very little time, and consuming almost ne of the length of the specimen.

A welding heat can thus be produced at any int without danger to the remainder of the ructure, and shapes of an intricate form can be ilt up. Highly skilled labor is not necessary the success of the operation, and this application of electricity is certain to become one of reat practical importance in the near future.

The steady advance in the matter of electrical "storage of energy" should not be overlooked. Secondary batteries or accumulators have been considerably improved, and their cost has been greatly reduced. Their practical use has considerably extended, and it may be confidently expected that they will in the near future justify by their performance the confidence which is reposed in them.

One of the best indications of this confidence, as well as of the assured success of the principal developments in electricity at the present time, is the fact that speculation and stock-jobbing is no longer the main object of those financially interested, and that most electrical enterprises have become safe and legitimate investments, paying reasonable dividends.

While much has been done in the practical utilization of electricity during the past few years, it may safely be said that much more has been accomplished in the development of its theory. The direction of this advance has been towards a better understanding of the real nature and origin of electrical phenomena. While it would not be at all in harmony with the plan of this book to undertake anything like an extended discussion of electrical theories, the importance of recent researches and the interest they have created justify a brief consideration of the subject.

The manner in which electrical and magnetic induction takes place has from the beginning excited the interest of physicists. From the time of Newton, philosophers have been unwilling to admit the possibility of what is generally known as "action at a distance." The discovery that light travels at a finite and measurable velocity almost forced the conclusion that space must be filled with a medium through and by which light and radiant heat were transmitted. All recent investigation has strengthened this view, and resulted in an enormous accumulation of facts only explainable on the hypothesis of the existence of an ethereal medium. In fact, one of the most distinguished philosophers of modern times has emphasized his own confidence in ether by declaring that there are better reasons for believing in its reality than in that of shoemaker's wax. Maxwell, through his study and exposition of Faraday's great work, was led to the belief that electric and electro-magnetic phenomena might, in a similar manner, be explained upon the hypothesis of a medium possessing certain mechanical properties, and he quickly saw that this medium might be and doubtless was the ether demanded by the undulatory theory of light.

The present century has produced no physicist at once more brilliant and more profound than Clerk Maxwell. Born at Edinburgh in 1831 and educated at Cambridge, he gave early promise of that genius which in a few years so enriched physical science that his death at a comparatively early age, almost before he had reached the prime of life, was regretted by philosophers of all lands, by whom he was universally esteemed as one of the foremost exponents of modern physics. He was early drawn to the study of electricity, and especially through the perusal of Faraday's papers. He saw that Faraday's method of conceiving and treating electrical phenomena was essentially mathematical, although lacking the conventional mathematical symbols. He became the mathematical expounder of Faraday's work, which he enriched and enlarged by means of the powerful methods of analysis of which he was master. Perhaps the most important of his many contributions was his electro-magnetic theory of light. In the development of this theory, in which the identity of the light ether and the electro-magnetic ether was assumed, he reached certain conclusions which ought to be valid if the fundamental propositions of his theory are correct. These conclusions have since been largely verified by experiment, and the tendency of physical research has been towards the confirmation of Maxwell's theory. Within the last two years, however, evidence in its favor has accumulated with wonderful rapidity, and of such a character as to leave almost no doubt as to the reality of Maxwell's hypothesis.

It is almost entirely embodied in a series of brilliant and elaborate investigations made by Dr. Hertz, of Carlsruhe, who, in their planning and execution, has exhibited great experimental skill, together with a keen appreciation of the meaning of electrical phenomena. To get some idea of their character, it will be well to refer to the oscillatory nature of an electric discharge, a mechanical illustration of which may be found in the behavior of a bent spring, or any other elastic body subjected to a strain. If a spring is bent, the work expended in the bending is stored in the spring as potential energy, assuming its elasticity to be perfect. If it be freed from restraint, there will generally follow a series of oscillatory discharges of this energy, or conversions of potential into kinetic energy, and *vice versa.* These rapid vibrations from side to side, passing from rest at the extremes of its motion to maximum velocity in the middle, would continue indefinitely were it not for the dissipation of energy through molecular and other frictions. The electric ether in a charged Leyden jar or other condenser is in a condition somewhat similar to that of a bent spring, and especially in the fact that energy is stored as "potential" in the charge. As long ago as 1842, Joseph Henry observed that the discharge of a condenser was oscillatory in its character, consisting of "several reflex actions backward and forward until equilibrium is attained." In 1847 Helmholtz wrote "that the discharge of a jar is not a simple motion of the electricity in one direction, but a backward and forward motion between the coatings in oscillation, which become continually smaller until the entire *vis viva* is destroyed by the sum of the resistances." In 1853 Sir William Thomson attacked the subject mathematically, and "packed the whole theory into an equation," the conclusions from which have been verified by many experiments. From

1870 to 1873, the nature of the oscillatory discharge from a Leyden jar was thoroughly investigated experimentally by Professor Ogden Rood. The rapidity with which these oscillations take place is governed by conditions in some degree analogous to those controlling the period of vibration of an elastic body, and it is especially worthy of note that the smaller the condenser the more frequent the oscillations. Dr. Oliver Lodge estimates that a gallon Leyden jar, discharged through a stout wire fifty or sixty feet long, gives rise to oscillations as frequent as one million per second; while in a pint jar, discharged in the ordinary manner by a short, good conductor, they are as frequent as fifteen millions per second.

These electrical oscillations must give rise to waves in the ether, precisely as the oscillations of a tuning-fork produce waves in the air; and the length of these waves will, of course, be equal to the velocity with which the wave is transmitted multiplied by its period. Assuming with Maxwell that the electric ether is identical with the light ether, and that therefore the velocity of transmission of these waves is approximately 186,000 miles per second, it is easy to calculate that the waves in the first instance will be about one thousand feet long, and in the second about sixty-five feet in length.

By diminishing the electro-static capacity of the apparatus, the period can be made still shorter, and the wave-length correspondingly less. For some years the existence of these waves has been accepted by physicists, but to Hertz belongs the great credit of having first actually *found* them in space, and for having established their existence by a series of experiments remarkable alike for their beauty and simplicity. It is impossible here to describe either method or results, except in the briefest possible manner. As to the method, it may be said that it was in principle somewhat analogous to the use of a resonator in acoustic experiments, which responds to and makes sensible any sound with which it is synchronous.

Hertz's "resonator" is very simple in form, consisting of a short metallic circuit broken by a small interval, across which sparks may pass. As to results, it is enough to say that he has been able to show that these waves obey all the laws, such as those of reflection, refraction, polarization, interference, etc., to which light-waves are subject, when proper consideration is given to the nature of the material employed to produce these various effects. They have been concentrated by metallic mirrors and refracted by huge prisms of pitch. Metals, which are conductors of heat and electricity, are opaque to them, while non-conductors or poor conductors are transparent. It is easy to see that, if the vibration frequency be made sufficiently great, these waves will possess all the essential characteristics of light-waves; and remembering that the smaller the capacity of the charged body the more rapid the oscillations of the charge when it is disturbed, it will appear that electric charges on atoms or molecules might readily oscillate thousands of millions of times per second, and thus light might be regarded as a *purely electrical phenomenon*, as affirmed by Maxwell. Altogether the discoveries of Hertz must take high rank as marking a distinct advance in electrical science, and especially as opening a wide field for investigation which promises rich rewards to the many now entering upon its exploration.

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